THE UNIVERSITY OF ALBERTA

SOME FACTORS AFFECTING
RETENTION OF SHORT TEMPORAL DURATIONS

by

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A THESIS

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ABSTRACT

The main purpose of this series of ten studies was to determine the short-term retention characteristics of temporal information. A second purpose was to determine the constraints and causes leading to a loss of temporal information when forgetting occurs. The method of reproduction was used. Temporal durations of 8 seconds or less were utilized. Two factors were investigated: (a) time-in-store, and (b) interference (capacity, proactive and structural). These factors were examined under conscious time estimation and mental counting cognitive strategies.

Results indicated different short-term retention characteristics between very short temporal durations (less than four seconds) and short temporal durations (more than four seconds) under a conscious time estimation cognitive strategy. Very short temporal durations were not subjected to the time-in-store factor. Further, they were not affected by any form of interference. Short temporal durations were influenced by the time-in-store factor. Further, they were subjected to structural interference. These results were discussed in relation to: (a) degradation of the trace when loss of temporal information was experienced under the time-in-store factor,

and (b) the use of different strategies on behalf of the subjects when loss of temporal information was demonstrated under the interference factor (structural form).

Results also indicated that the retention characteristics for temporal durations of 8 seconds or less under a mental counting cognitive strategy were superior to those demonstrated under conscious time estimation cognitive strategy. Temporal durations (less than four seconds) under a mental counting cognitive strategy were influenced by the time-in-store factor when subjects reproduced under a subject-defined rehearsal or an experimenter-defined rehearsal. Further, those durations were not subjected to any appearance of interference. Loss of temporal information was eliminated when subjects recalled those temporal durations under specific instructions using an experimenter-defined rehearsal. These results were discussed in relation to the use of specific instructions which facilitated the retention of time.

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Michel Guay

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Introduction

The experimental study of human time perception began approximately one hundred years ago (Vierordt, 1868), but has not attracted much attention for some time. Thus, some years ago Adams (1964) in a review wrote: "Time perception is a venerable, tired topic in psychology that interests very few active investigators any more, perhaps because no one bothered to explore the mechanisms of time perception and how it might enter into meaningful interaction with other mechanisms" (p. 197). In recent years, however, interest in the psychology of time and the "mechanisms of time perception" have increased considerably. If one tries to summarize some of the hypotheses on the fundamental mechanisms of time perception which have been discussed or which were implicitly assumed, one will find two basic approaches.

The first approach proposes a pulse counter model based on the hypothesis that man experiences time via a time keeper, driven by physiological or hypothetical periodic processes (Hoagland, 1933; Orme, 1969; Pöppel, 1972; Treisman, 1963). The second is a cognitive approach based on an information processing view of man's behavior (Frankenhaeuser, 1959; Hicks, Miller, Gaes and Bierman, 1977; Michon, 1972, 1975; Ornstein, 1969; Vroon, 1976). On the one hand, time means information to the subject

(Michon, 1972) and on the other hand it is suggested that subjective time is a direct function of ongoing processes in the encoding, storing and retrieving of information (Ornstein, 1969).

Although there has been a revival in the study of problems of the perception of time, little is known on the memory of time and no governing theory seems to exist for temporal information. Furthermore, despite an effort for the the study of long-term retention of time (Block, 1974; Fraisse, 1967; King, 1963; Ornstein, 1969; Young and Sumner, 1954), little work has been done concerning the short-term retention of time (DuPreez, 1967; Hawkes, Ray and Hayes, 1974; Kowalski, 1943). As for the latter, studies on time estimation to date have not led to the conclusion that the memory for time fades over a retention interval (DuPreez, 1967; Kowalski, 1943; Pöppel, 1973). Nor does there appear to be a significant effect of interference on the to-be-remembered item (tbri) (Hawkes, Ray and Hayes, 1974; Kowalski, 1943) for time. Moreover, basic questions pertaining to the encoding, retention and retrieval of that type of information have not really been answered (Bartlett and Tulving, 1974; Guenther and Linton, 1975; Michon, 1975). Therefore, if a clear understanding of how the human performer deals with temporal information is to be provided, more sound efforts should be directed towards answering the above question.

Consequently, this series of investigations will be on the experience of time (durations which are less than 10 seconds). More particularly it will be on the short-term memory of time (single item). Frankenhaeuser (1959) states that since experience of time is closely related to the perception and retention of the events filling the time interval, memory is an inherent characteristic of time as it is experienced. However, it is difficult to distinguish perfectly between the memory and the perception of time (Fraisse, 1967). Therefore, throughout this program of experiments, the perception of time will refer to the more or less immediate experience of short time intervals while the memory of time will refer to the experience of time intervals in retrospect (retention intervals which are less than 60 seconds) (Fraisse, 1967; Fraisse and Florès, 1956; Frankenhaeuser, 1959).

There are three basic justifications for studying short-term memory of time: (a) there have been few studies on this topic, (b) most of those studies measured the mean reproduction which is generally considered the poorer of a number of associated measures, and (c) in those studies, no one examined whether temporal and movement information have the same retention patterns.

Short-term memory of time has received little research interest when compared to movement information which has been the most closely related, continuous dimension investigated for single tbri. The way that scholars

have traditionally approached the motor short-term memory problem will be employed throughout this series of investigations. The typical experimental paradigm they used for the examination of short-term retention was the presentation of a criterion item, a retention interval which may or may not involve a distrator task, and then recall of the criterion item. This paradigm was initially utilized by Brown (1958) and Peterson and Peterson(1959) in the verbal domain, and later by Adams and Dijkstra (1966) in the motor area. Following their lead, numerous researchers have investigated retention and interference effects in short-term motor memory (Ascoli and Schmidt, 1969; Posner, 1967; Stelmach, 1969) and more recently, the encoding and retention characteristics of movement attributes (Diewart, 1975; Hall and Leavitt, 1977; Laabs, 1973; Marteniuk, 1973).

The majority of investigations in the motor domain have examined the retention characteristics of distance and location movement attributes in some detail. Collectively, the research on distance, and location information warrants several general conclusions. Location is encoded in memory so that relatively accurate reproduction is possible, and location information displays retention characteristics similar to visual information. However, distance is encoded in a manner which does not permit it to be utilized for movement reproduction with the same degree

of accuracy as location information. Furthermore, with respect to retention characteristics, distance information has produced some very conflicting results. In some cases distance has been found to spontaneously decay over a retention interval and in other studies the retention of distance has conformed to that of location.

Short-term memory can be defined simply as a memory system that rapidly loses information in the absence of sustained attention of that material. It is thought to involve about the first 60 seconds following presentation of the information, after which it is either lost or transferred to long-term memory (Marteniuk, 1976). As mentioned previously, in order to study the basic short-term memory phenomenon for temporal information (single item), the Peterson procedure should be employed. Therefore, the factors of interest in the following investigations will be (a) retention intervals (time-in-store) and (b) interference. Retention intervals can vary in length from immediate recall to any time up to about one minute. During the retention interval the individual can think about or actually rehearse the information presented to him, in which case he is said to be attending to the information. Alternatively, either he can be made to perform an interpolated task that is unrelated to the to-be-remembered information (capacity interference), or he can be made to perform some task that is thought to interfere with the

presented information (structural interference). In either condition, the individual cannot attend to the to-be-remembered material, and any decrement in its recall can be attributed either to lack of attention during the retention interval or to direct interference from information presented during the retention interval. It appears, therefore, that some of the forgetting in short-term retention may be attributed to either capacity interference or structural interference on a given trial. Forgetting may also be ascribed to interference from previous trials (proactive interference) or to factors other than interference (decay).

Consequently, these two factors (time-in-store and interference) will be examined in the following program of experiments. Certainly there are more than two factors that may affect the short-term retention of temporal information. However, it is of prime importance to know how long temporal information can be stored in short-term memory and to distinguish between the causes of the decrements in recall due to items presented on a given trial (related and unrelated interpolated tasks) and on successive trials (proactive interference). Such an approach for the study of the short-term retention process has been used before in the verbal and motor domains. The retention characteristics of different temporal cues must be obtained if the memory for time is to be understood. Moreover, some

knowledge of the limitations for the short-term memory process of the human performer for time is very important if one wants to communicate those theoretical conclusions in terms of practical situations.

Therefore, to further advance the understanding of how the human performer deals with temporal information, two questions will be answered:

1. what are the short-term retention characteristics of different reproduction cues, and
2. if forgetting occurs, what are the constraints or causes leading to such a loss?

The research to be reported is an effort to answer these two questions. Few real life situations require immediate responses to signals because of the requirements of other duties. Yet if the memory for time is important, such delays and duties must not affect the memory for time unduly.

The following program of experiments was divided into four sections. The perceptual characteristics demonstrated in human time estimation under conscious time estimation as opposed to experimenter-defined cognitive strategies are examined in Section 1 (Experiment 1). The effects of time-in-store and capacity interference factors on time estimation appear in Section 2 (Experiments 2, 3 and 4). Rehearsal and proactive interference are the two factors considered in Section 3 (Experiments 5, 6 and 7).

Finally, the effects of structural interference on time estimation are questioned in Section 4 (Experiments 8, 9 and 10). The above factors were investigated under conscious time estimation and mental counting cognitive strategies. Each section consists of: (a) a general purpose, (b) the various experiments, and (c) a summary. A general discussion of this series of studies follows Section 4.

Apparatus Calibration

Temporal durations of eight seconds or less were used in this research program. The temporal durations used were either one, two, four or eight seconds long. The Hunter Decade Interval Timers used in the following experiments had prior to its calibration a value of $\pm$ 3% absolute accuracy for those durations. Based upon these scores and in order to improve the absolute accuracy of the temporal durations, the setting on the Hunter Decade Interval Timers was adjusted prior to each experiment within $\pm$ 1% of the desired temporal durations. Thus, several trials were run until the range of the temporal durations was approximately equal or less than $\pm$ 1% of the duration magnitude.

Section 1

General Purpose of Section 1

The general purpose of Section 1 (Experiment 1) was to determine whether there is a difference between the characteristics demonstrated in human time estimation under conscious time estimation as opposed to experimenter-defined cognitive strategies (time-aiding techiques). Conscious time estimation will be considered as another cognitive strategy and is likely often what is meant when subjects are instructed to refrain from employing time-aiding techniques (Buckolz and Gervais, 1976). On the other hand, experimenter-defined cognitive strategies will refer to a variety of strategies that the subjects will be required to use in order to improve their estimates of time length and thus yield time estimates whose characteristics might differ from those where no time-aiding techniques are permitted.

In addition to providing some indication of possible differences between the various performance modes, these data will serve as a basis for separating and controlling the use of the reproduction cues in the other experiments. Failure to adequately control for the use of different cues is bound to lead to conflicting and uncertain results in time estimation studies.

Experiment 1

Cognitive Strategies

in

Human Time Estimation

Many mechanisms have been proposed to explain how a subject keeps time (for a review see Doob, 1971; Orme, 1969; and Vroon, 1976). In situations involving motor tasks, it has been hypothesized that proprioception can serve as one possible time-keeping mechanism in the accurate anticipatory timing of movement responses (for a review see Christina, 1976; and Dickinson, 1974). Furthermore, it is becoming evident that alterations in the temporal component of a motor response can occur as a result of several cognitive strategies. By-products such as verbalization (Ellis, 1969), proprioceptive mediation (Adams and Creamer, 1962; Ellis, Schmidt and Wade, 1968; and Schmidt, 1971) or counting (Buckolz and Gervais, 1976; Buckolz and Guay, 1975; and Getty, 1976) may be used by the subject to estimate time. As a consequence such cues remove the subject from the realm of time-keeping or conscious time estimation (Buckolz and Guay, 1975) and usually produce a better performance by increasing the accuracy or reducing the variability of the estimates.

The fact that time-aiding techniques ameliorate performance of time estimation can be seen to be intuitively obvious. Nevertheless, the identification of the most adequate cognitive strategy is a more difficult problem.

It is even more difficult to determine which cue or cues are the most effective. Few studies have been done in that direction (Ellis, 1969; Ellis, Schmidt and Wade, 1968; Goldstone, Boardman and Lhamon, 1958; Schmidt and Christina, 1969). Goldstone, Boardman and Lhamon (1958) compared the effect of two forms of cognitive strategies. The first was strictly a mental counting strategy. The subject had to estimate an interval of 30 seconds by counting to himself at a rate of one count per second. The second strategy was identical to the first except that the seconds were counted out loud and the subjects could use finger and foot tapping. According to the above authors, the latter form of cognitive strategy permitted the subjects to use proprioceptive cues, namely the movements of the lips at regular intervals. Their results indicated the superiority of a cognitive strategy with a proprioceptive character. However, in their study auditory and proprioceptive cues were confounded. Several years later, Ellis, Schmidt and Wade (1968) found that a long movement (65 cm.) produced better performance for estimating a two seconds time length than did a small movement (2.5 cm.). They concluded that the greater the amount of the proprioceptive cue, the better the estimate. Similar results were obtained by Christina (1971) and Ellis (1969). In Christina's (1971) study, subjects with a high level of movement-produced feedback anticipated temporally with greater accuracy a time length of 1.5 second than did subjects with a low

level of movement-produced feedback. In Ellis' (1969) study, subjects were more accurate in reproducing a two seconds time length while spelling three and four letter words than they were while spelling two letter words. However, a high level of proprioceptive cues did not always results in a better performance (Christina, 1970; Schmidt and Christina, 1969).

According to the above studies the following conclusions are of interest: (a) an increase in the number of cues ordinarily results in a better recall of the to-be-remembered item (tbri), and (b) an increase in the level of a particular cue normally produces a better recall of the original criterion. Few studies have been directed toward isolating the cues that subserve temporal information. Consequently, the purposes of this study were to explore the validity of those conclusions and to determine which cues will receive more attention in the following experiments. In order to examine this validity, four forms of cognitive strategies, each increasing in the number of cues and short time lengths, were used under the method of reproduction.

Method

Subjects

Twelve volunteer graduate students in physical education at the University of Alberta were used in the

experiment.

Apparatus and Task

A time estimation-reproduction task was used (Bindra and Waksberg, 1956). This required the subjects to initiate the occurrence of the time interval to be estimated (criterion) and then, immediately after the presentation of the criterion, to initiate and terminate the recall of the to-be-remembered item (tbri). The self-paced task for the presentation was employed because of the possible interference of an experimenter-paced task for the presentation with short durations and to help offset a motivation decrease in the subject (Buckolz, 1972). In addition, rigid pacing (for the presentation and the response) normally used in time estimation studies may have accounted for the lengthening effect obtained (Treisman, 1963).

The subjects sat facing a table upon which two pistol grip shaped handles were placed thirteen inches apart. Each grip had a trigger that was directly connected to a microswitch. The left grip and trigger operated by the subject's left hand was connected to an interval timer (Hunter 100-C) which in turn was connected to a small red neon lamp (Snaplite). When the subject depressed the trigger in a squeeze-then-release manner, the interval timer turned the red light on. The light remained on until the interval timer turned it off

following the prescribed criterion time length which was pre-set by the experimenter. The right pistol grip and trigger, operated by the subject's right hand was connected to a clock (Hunter 120-C) set for milliseconds. A small red coloured neon lamp (Snaplite) was connected in parallel with the clock and came on when the right trigger was squeezed. Both the red "criterion time length" light and the red "recall of the tbri" light were placed in front of the subjects and positioned nearest to their respective triggers. According to Brown and Hitchcock (1965), modality of stimulus presentation and of reproduction had no consistent effect on time estimation. Previously, Hirsh, Bilger and Deatherage (1956) had found no audio-visual difference using the method of reproduction with short durations. Consequently, the visual presentation-visual response was utilized in the present study.

Note that to obtain the criterion time length, the subject had to merely squeeze then release the left trigger and grip. In order for the subject to reproduce to criterion at recall, he had to squeeze and hold the right hand trigger for the full temporal length of the tbri. Only visual cues were provided to the subjects.

For one of the four cognitive strategies described below, a tone generator (Eico 377), an amplifier and a set of earphones were used as a circuit. This circuit was utilized in order to mask auditory cues by

simulated white noise.

Design

Four levels of cognitive strategies were used: (a) conscious time estimation (CTE), (b) mental counting (MC), (c) counting aloud without auditory cues (CAWOA), and (d) counting aloud with auditory cues (CAWA). These four levels of cognitive strategies were combined factorially in a treatment by subject's design with three levels of criterion time length; namely 1, 2 and 4 seconds. Twenty-five trials were given for each of the 12 treatments. Of those trials, five were warm-up trials and the last twenty were experimental trials and subject to analysis.

Procedure

The subjects were given a number of trials to familiarize themselves with the equipment. They attended three separate sessions of approximately 60 minutes each. The 12 treatment conditions were assigned to the subjects (4 treatments per session), with the order of occurrence determined by a random 12 X 12 balanced Latin Square. The instructions to the subjects concerned four points: (a) the subjects were asked to be as accurate as possible, (b) the subjects were asked to express and demonstrate their understanding of the task, (c) the subjects were asked not to use any time-aiding techniques when such

instruction was given under conscious time estimation cognitive strategy (i.e. the experimenter explained thoroughly what was meant by time-aiding techniques, giving examples of the various kinds), and (d) the subjects were asked to use the experimenter-defined cognitive strategies (mental counting or counting aloud) when such cognitive strategies were experienced (i.e. the experimenter explained thoroughly what was meant by mental counting and counting aloud).

Data Analysis

The dependent variables used were: (a) average (mean) performance (AP), (b) absolute error (AE) or unsigned error, (c) signed constant error (CE) or mean signed algebraic error, and (d) variable error (VE) or the standard deviation of the CE or AP.

Results

Raw Data

The raw time estimation data for all treatment conditions and for each subject were visually inspected. In only a few cases did the data show a lengthening or shortening effect whereby time estimations become longer and longer or shorter and shorter as the number of trials increase (Falk and Bindra, 1954; Treisman, 1963). Consequently, the twenty trials for each subject

were reduced to a simple mean. This simple mean for each subject under each treatment condition was termed average performance. From average performance it is possible to calculate the constant error (constant error equals average performance minus the appropriate criterion time length). Average performance touches briefly on the concept of accuracy while constant error is a measure of accuracy and direction. In the present study, average performance was considered as a measure of discrimination.

Time Length

Average performance increased significantly, $F\ (2,22) = 4382.92$, $p < .01$, as the time lengths increased, a relationship which held for all levels of cognitive strategies as evidenced by the non-significant interaction between time lengths and cognitive strategies ($p > .05$). A Scheffé's test for the time lengths' main effect revealed that the three time lengths were significantly different from one another ($p < .05$). This suggests that subjects were able to maintain their estimates of one, two and four seconds as distinct events over experimental conditions; and that when errors arose they were not due to the subjects confusing the three time lengths perceptually.

A significant effect for absolute error, $F\ (2,22) = 28.76$, $p < .01$, was found for time lengths. Significant differences between all time lengths were revealed by the

Scheffé's test ($p < .05$). Subjects produced larger errors as the time lengths increased. However, there was an interaction between time length and cognitive strategy, F (6,66) = 5.88, $p < .01$, in the absolute error analysis. As illustrated in Figure 1, the interaction effect was almost totally due to the two and four seconds time lengths when held in memory under the mental counting (MC), counting aloud without auditory cues (CAWOA) and counting aloud with auditory cues (CAWA) cognitive strategies.

A significant effect for variable error scores, F (2,22) = 35.64, $p < .01$, was found for time lengths. Significant differences between all time lengths were revealed by the Scheffé's test ($p < .05$). Subjects were more variable as the time lengths increased. However, an interaction between time length and cognitive strategy also occurred, F (6,66) = 11.14, $p < .01$, in the variable error analysis. The interaction effect was almost totally due to the four seconds time length when held in memory under the mental counting (MC), counting aloud without auditory cues (CAWOA) and counting aloud with auditory cues (CAWA) cognitive strategies (see Figure 2).

With respect to the constant error measurement, a significant effect, F (2,22) = 6.71, $p < .01$, was found for time length. A significant difference between the two and four seconds time lengths was revealed by the Scheffé's test ($p < .05$). Subjects over-estimated the two seconds length to a higher degree than the four seconds

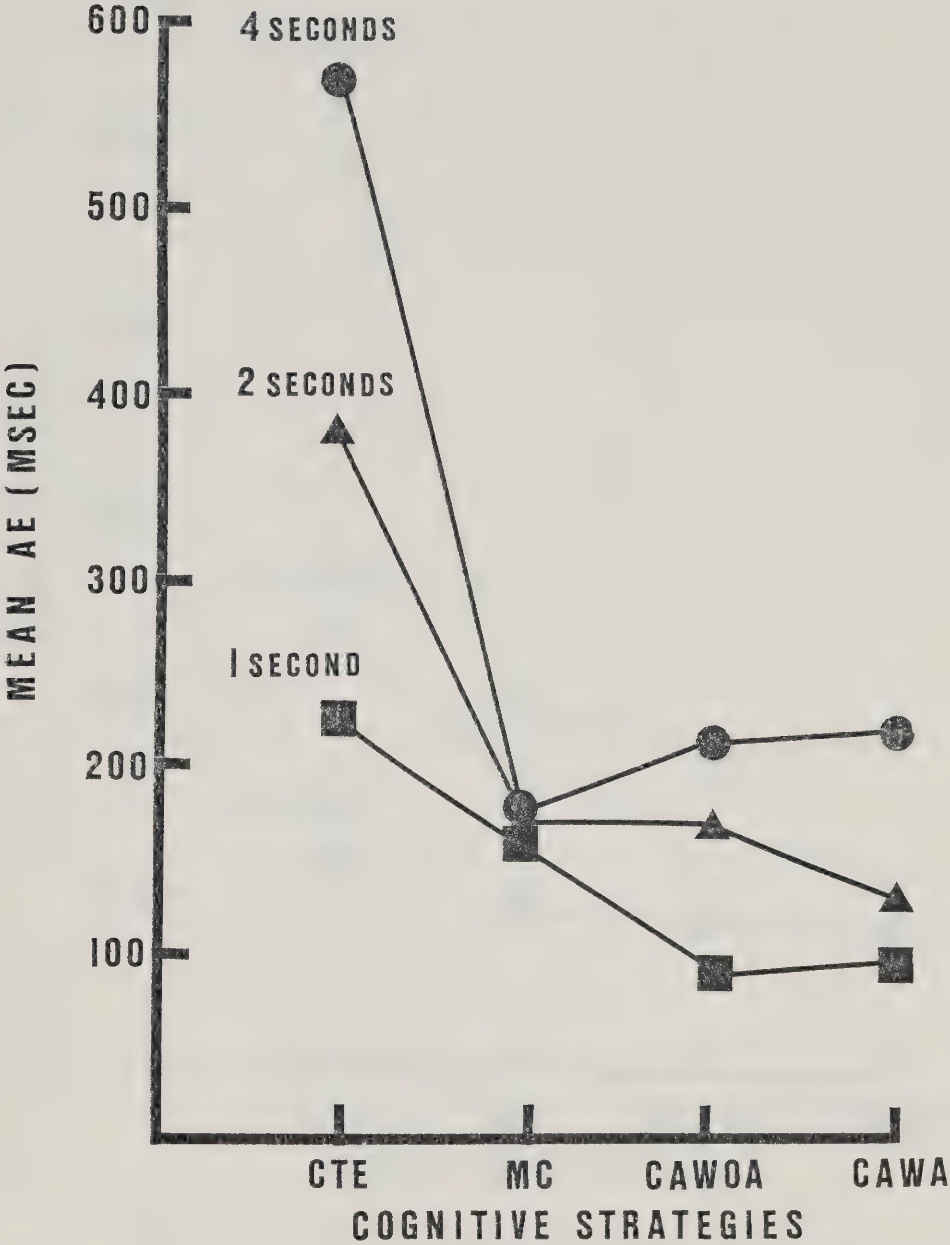


Figure 1 Mean absolute error (AE) for time lengths (1, 2 and 4 seconds) as a function of the cognitive strategies (CTE = conscious time estimation; MC = mental counting; CAWOA = counting aloud without auditory cues; CAWA = counting aloud with auditory cues)

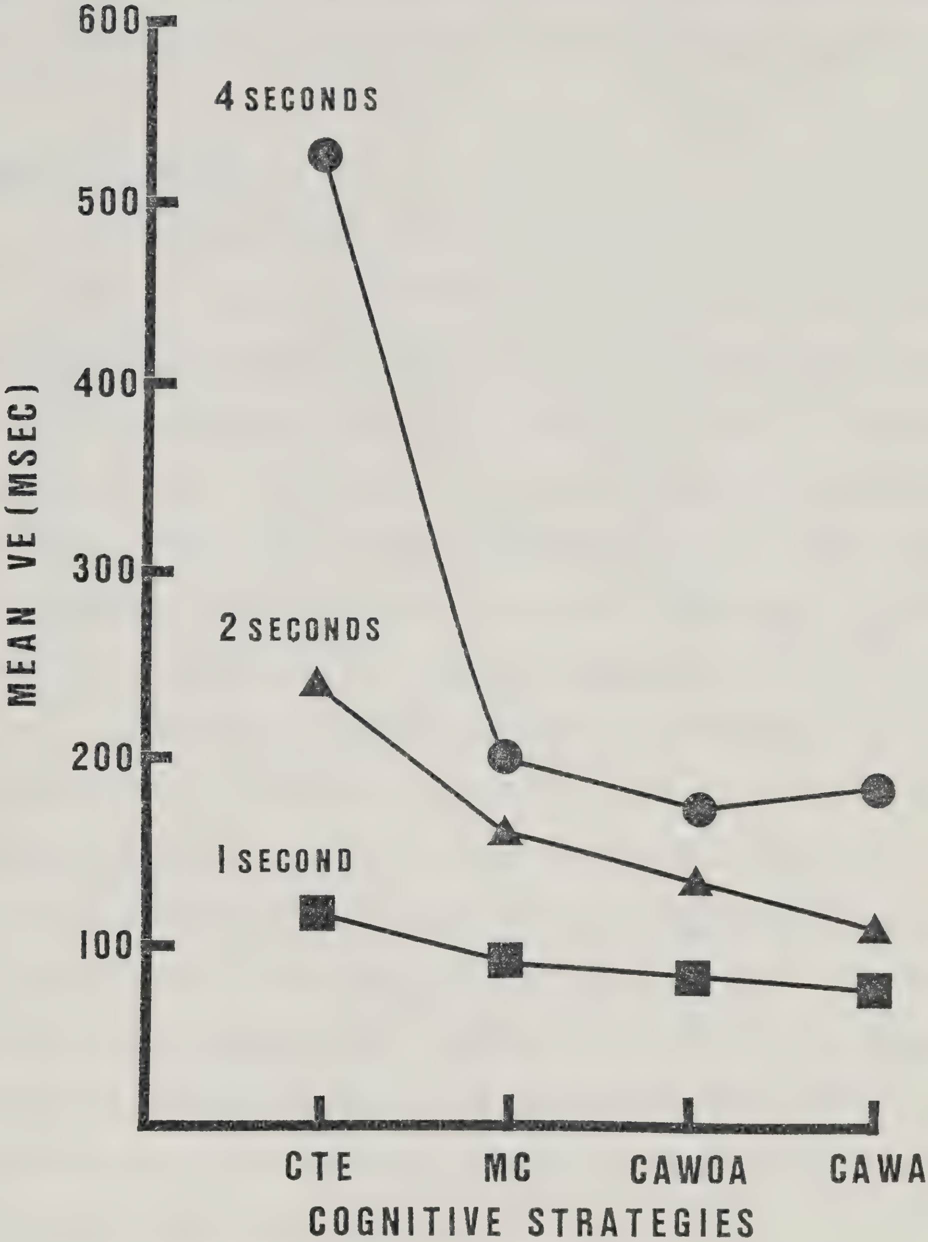


Figure 2 Mean variable error (VE) for time lengths (1, 2 and 4 seconds) as a function of the cognitive strategies (CTE = conscious time estimation; MC = mental counting; CAWOA = counting aloud without auditory cues; CAWA = counting aloud with auditory cues)

time length. The interaction between time length and cognitive strategy for CE was not significant (*p* $>$ .05).

Cognitive Strategy

A significant effect, *F* (3,33) = 4.27, *p* $<$ .05, was found for average performance across the cognitive strategies. Because of the non-significant time length by cognitive strategy interaction noted earlier, a Scheffé's test (*p* $<$ .05) was run on the main effect of cognitive strategy. The significant difference for all time lengths was between conscious time estimation (CTE) and counting aloud with auditory cues (CAWA) (see Figure 3).

The main effect of cognitive strategy was significant for absolute error, *F* (3,33) = 9.70, *p* $<$ .01. Because of the significant time length by cognitive strategy interaction noted earlier, a Scheffé's test (*p* $<$ .05) was run on the simple main effect. The significant differences were between conscious time estimation and all other cognitive strategies for the two and four seconds time lengths. Subjects were less accurate under conscious time estimation.

The analysis of the variable error scores resulted in a significant cognitive strategy main effect, *F* (3,33) = 16.13, *p* $<$ .01. The significant time length by cognitive strategy interaction reported above necessitated the calculation of simple main effects using Scheffé's test (*p* $<$ .05). Conscious time estimation was signific-

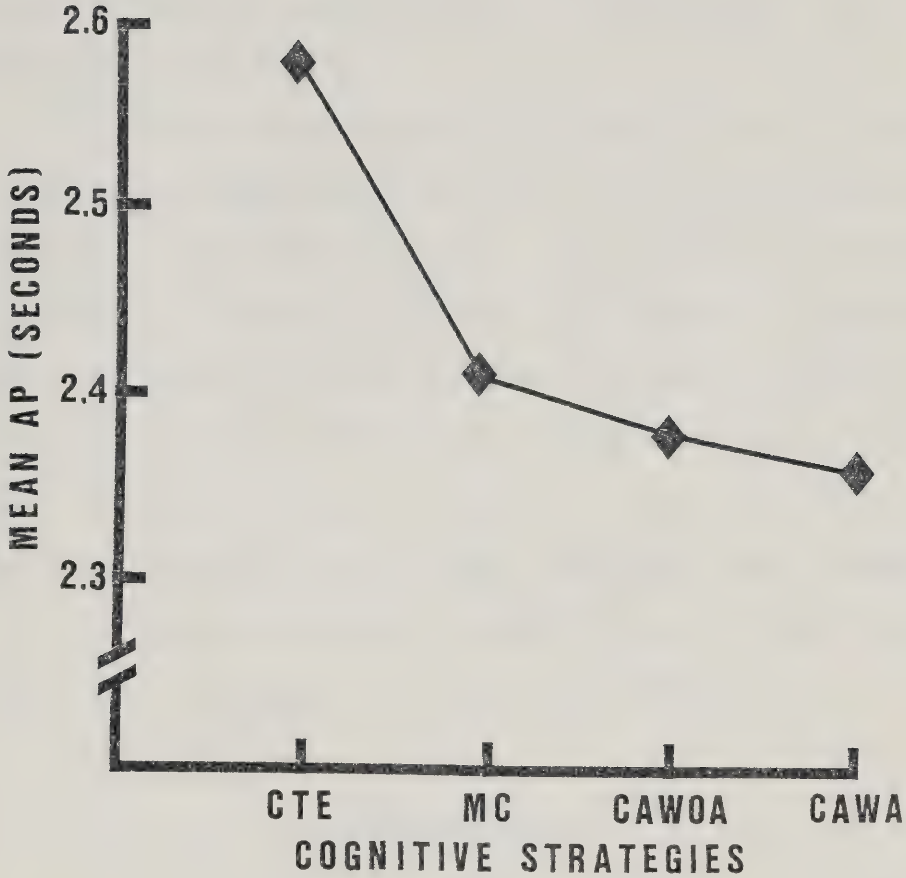


Figure 3 Mean average performance (AP) for subjects recall performance of time lengths as a function of cognitive strategies (CTE = conscious time estimation; MC = mental counting; CAWOA = counting aloud without auditory cues; CAWA = counting aloud with auditory cues)

antly more variable than counting aloud with auditory cues for the two seconds time length. In addition, conscious time estimation produced significantly more variability than all other cognitive strategies for the four seconds time length.

A significant effect, $\underline{F}$ (3,33) = 4.27, $\underline{p} < .05$, was found for signed constant error across the cognitive strategies. A Scheffé's test ($\underline{p} < .05$) was run on the main effect of cognitive strategy and revealed significant differences between conscious time estimation (CTE) and counting aloud with auditory cues (CAWA) for all time lengths. As illustrated in Figure 4, subjects over-estimated to a greater extent under conscious time estimation.

The various error scores for each time length and cognitive strategy are summarized in Table 1.

Discussion

Time Length

The fact that average performance differed significantly for all contrasts of time lengths indicates that the subjects were capable of reliably discriminating the time lengths used. This may be useful for future design purposes.

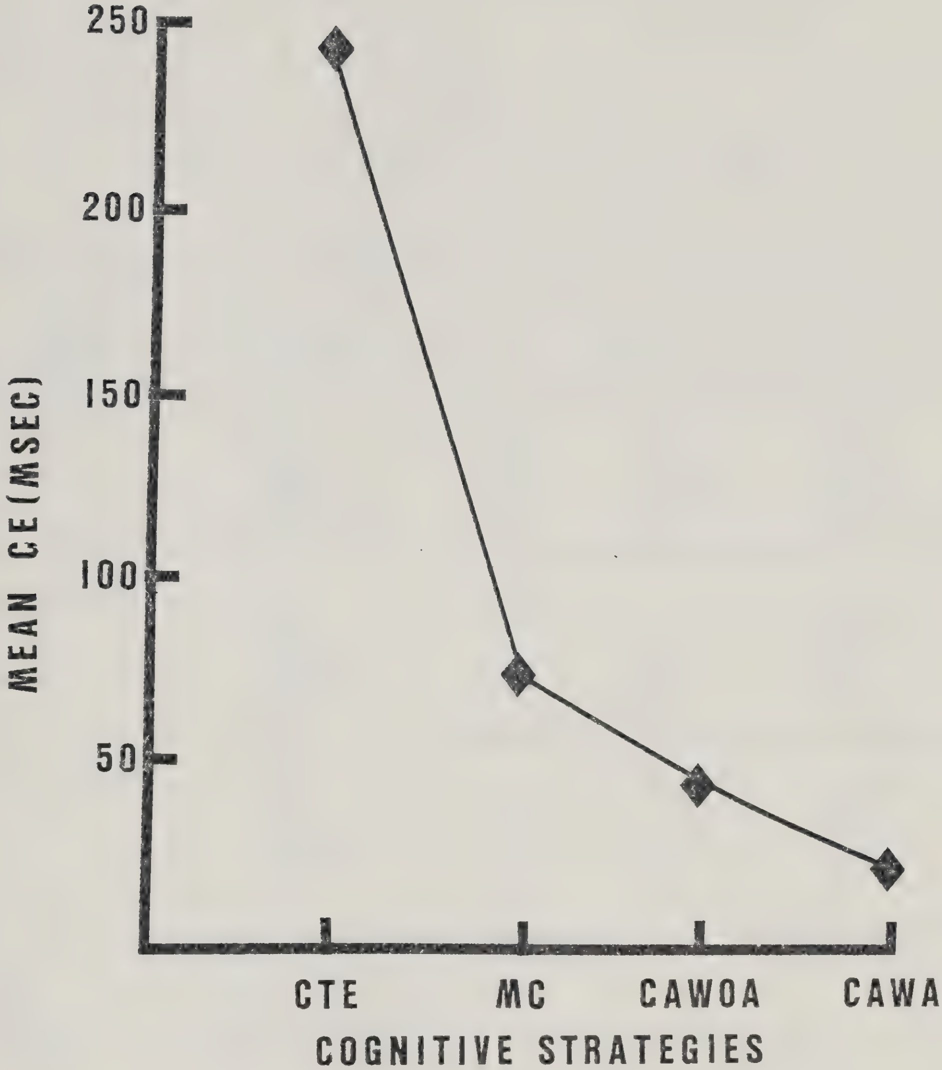


Figure 4 Mean constant error (CE) for subjects recall performance of time lengths as a function of cognitive strategies (CTE = conscious time estimation; MC = mental counting; CAWOA = counting aloud without auditory cues; CAWA = counting aloud with auditory cues)

Table 1

Mean VE, AE, AP and CE in Milliseconds for

Time Length and Cognitive Strategy

Time Length	Cognitive Strategy[a]	Dependent Measure[b] VE	AE	AP	CE
1 second	CTE	116	225	1189	189
	MC	90	155	1142	142
	CAWOA	80	84	1049	49
	CAWA	76	89	1067	67
2 seconds	CTE	240	381	2324	324
	MC	157	159	2105	105
	CAWOA	129	164	2081	81
	CAWA	104	125	2063	63
4 seconds	CTE	526	566	4208	208
	MC	197	174	3978	- 22
	CAWOA	175	208	4110	1
	CAWA	179	214	3937	- 63

[a]CTE = conscious time estimation
MC = mental counting
CAWOA = counting aloud without auditory cues
CAWA = counting aloud with auditory cues

[b]VE = variable error
AE = absolute error
AP = average performance
CE = constant error

Cognitive Strategy and Time Length

Firstly, when comparing conscious time estimation to the other three levels of cognitive strategies, the following observations were of interest. The effectiveness of mental counting (MC), counting aloud without auditory cues (CAWOA) or counting aloud with auditory cues (CAWA) in providing better cues for time estimation appeared to depend upon the length of time being estimated. This finding has been reported previously by Buckolz and Gervais (1976). The present investigation revealed that MC, CAWOA and CAWA improved time estimation accuracy (AE) significantly when compared to conscious time estimation for the two and four seconds time lengths. Moreover, significant reductions in variability between conscious time estimation and MC, CAWOA or CAWA did not occur for all time lengths. It seems that as the time length decreases, the variability between conscious time estimation and the other three levels of cognitive strategy tends to stabilize. The variability of the two and four seconds time length estimates was reduced under some levels of cognitive strategy, while the one second time length estimates did not improve (i.e. there were no differences between the various cognitive stategies). A similar finding for the one second time length variability was reported by Buckolz and Gervais (1976). For the two seconds time length only CAWA was different from conscious time estimation, while the latter differed from MC, CAWOA

and CAWA for the four seconds time length.

It is perhaps not surprising that all subjects are inefficient in using MC, CAWOA or CAWA beneficially when estimating short lengths of time. Firstly, compatible with this fact are the results from a study by Davis (1962) who pointed out that the rate of counting is an important factor in estimating time. For example, some subjects might have used a rate of 3 units per second, while Davis (1962) showed that a rate of 2 units per second is more accurate and less variable. This time-filling of 2 units per second was also found in a study done by Ellis (1969). Secondly, for a number of subjects, a subject-defined cognitive strategy might be more effective than the experimenter-defined cognitive strategies used in the present study. Finally, the potential of an individual in the reproduction of time (range of 0.1 to 1.0 second) might be obtained under conscious time estimation and the introduction of a cognitive strategy might have no effect or perhaps produce a negative effect (poor performance).

When comparing mental counting, counting aloud without auditory cues and counting aloud with auditory cues, the following points were of interest. For all dependent measures of performance there was no difference between the above three cognitive strategies. These results are not supported by Goldstone, Boardman and Lhamon (1958) who obtained differences between mental counting

(MC in this study) and counting aloud (CAWA in this study). The discrepancy between the two studies is probably due to the time lengths used. Perhaps one might expect that as the time length increases, one kind of cognitive strategy has an advantage over the other. Consequently, the rate of counting as well as the number of counts which correspond to a particular time length seem to be the important cues used by the subjects for MC, CAWOA and CAWA cognitive strategies. Whether the rate and the number are obtained under mental counting or counting aloud with or without auditory cues is not very important for the time lengths of the present study.

Moreover, the present results lead us to believe that the introduction of proprioceptive cues (speech muscles for counting aloud without auditory cues) or the equivalence of proprioceptive feedback given by this activity does not result in better recall of the to-be-remembered item compared to the mental counting which may not provide such cues. However, Aarons (1971) provided a further complication to the problem when he stated that muscular activity frequently occurs in the laryngeal area during subvocalization and that such activity might not be present in all individuals. Therefore, proprioceptive feedback might have been present and if differences were to be obtained in a later study, individual differences should be controlled.

The addition of auditory cues did not produce a better performance over MC and CAWOA cognitive strategies. Perhaps the major reason was the intelligibility or articulation of the words used in this investigation. Words such as "one, two, three, four", etc. are common to all subjects and the auditory feedback is not of prime importance. For example, one might question if different results would be obtained between CAWOA and CAWA if the subjects were asked to count aloud in German and for longer time lengths.

The general conclusions of Experiment 1 are: (a) the effectiveness of mental counting, counting aloud without auditory cues and counting aloud with auditory cues over conscious time estimation in terms of accuracy and variability depends on the time length used, (b) an increase in the number of cues does not necessarily produce a better performance, and (c) an increase in the level of a particular cue does not produce a better performance.

Summary of Section 1

Differences between the perceptual characteristics demonstrated in human time estimation under conscious time estimation as opposed to experimenter-defined cognitive strategies for short time lengths were determined in Section 1. In terms of those results, conscious time estimation and mental counting cognitive strategies were chosen as the two performance modes which will be examined in further detail in the following sections. Although a wide array of information is available to aid in temporal reproduction, studies of temporal short-term memory have given little attention to the specific cue (or cues) the subject may use during recall. Researchers might have attempted to isolate these cues, but did not determine their retention characteristics. If different reproduction cues have different retention characteristics, then failure to adequately control for the use of different cues is bound to lead to conflicting and uncertain results.

Section 2

General Purpose of Section 2

The purpose of Section 2 (Experiments 2, 3 and 4) was to determine the short-term retention characteristics of temporal information when subjects experience time under a conscious time estimation cognitive strategy (Experiments 2 and 3) and a mental counting cognitive strategy (Experiment 4) condition.

The question of whether or not temporal information is lost as a function of time (unfilled interval) is a crucial one for the development of a theory of temporal short-term memory and will be investigated. An analysis of what happens to temporal information when a non-temporal interpolated task (capacity interference) is presented during the retention interval will be considered. Results will also be compared to motor information.

Experiment 2

Conscious Time Estimation

and

Retention of Time

The retention of to-be-remembered motor items may depend upon the manner and depth to which those items are encoded (Lockhard, Craik and Jacoby, 1976). The result is that different types of encoded material may have different and unique retention characteristics (Ellis, 1973). The type of information that may be encoded into a single to-be-remembered item (tbri) includes velocity (Marteniuk, Shields and Campbell, 1972; Woodworth, 1899), timing (Marteniuk, Shields and Campbell, 1972), acceleration (Hall, 1977), torque (Wilberg, 1969), direction (Hall and Leavitt, 1977), distance, and location, among others. These various movement correlated characteristics appear to enhance or distort the subject's ability to reproduce (recall) the specified movement items from memory.

Unlike movements, temporal items may not necessarily have the variety of correlated information available for encoding into the tbri. Consequently one may question whether temporal and motor information have the same retention patterns, and if different magnitudes affect the fidelity of the tbri.

A variety of operational techniques have been developed: verbal mediation (Ellis, 1969), proprioceptive

mediation (Schmidt, 1971), or time-filling using motor tasks to keep track of temporal information (Buckolz and Guay, 1975). Unfortunately the use of such techniques confounds both the estimation and retention of temporal items with those of movement (Buckolz and Guay, 1975), thereby removing the subject from a purely temporal task. This is particularly true when time-keeping is the temporal task demanded of the subjects. Buckolz (1975) observed that under such conditions the extent to which time-keeping contributed to the temporal component of a given motor response cannot be assumed. It is unlikely, however, that an absolutely pure temporal task could be established since even in the least complicated instance it is the subject who must physically terminate the reproduction of the time interval being recalled. Consequently, a complete description of the subject's physical involvement in the temporal task is a minimum requirement if the retention characteristics of time are to be interpreted.

Temporal delays, though common in real-life situations, seldom appear in studies of time where the effects of retention are considered important (DuPreez, 1967; Hawkes, Ray and Hayes, 1974; Hawkes, Worsham and Ray, 1973; King, 1965, 1966; Kowalski, 1943; Richards and Livingston, 1966; and Vroon, 1970). One might expect the memory for time (the time intervals being referred to are those of short duration, i.e. less than 10 seconds) to have retention characteristics, over an unfilled

delay interval of 60 seconds or less, similar to those found in verbal (Melton, 1963; Peterson and Peterson, 1959) and motor (Girouard, 1975; and Hall and Leavitt, 1977; Marteniuk, 1973) memory. That is, in the presence of sustained attention the tbri is usually preserved over the delay interval prior to recall. However, when an interference task is interpolated during the delay interval, the tbri is usually affected, resulting in a deterioration of performance at recall.

Studies on time estimation to date have not led to the conclusion that the memory for time fades over a retention interval (see Table 2). Retention intervals from 0.4 up to 120 seconds were used by DuPreez (1967), Hawkes, Ray and Hayes (1974), Kowalski (1943), McNutt and Melvin (1968), Pöppel (1973), Richards and Livingston (1966) and Vroon (1970). Nor does there appear to be a significant effect of interference on the tbri for time (Hawkes, Ray and Hayes, 1974; Kowalski, 1943). The manner in which the subjects were controlled during the interference conditions of the above two studies is, however, open to question. Both studies left open the possibility that the subjects may have actually rehearsed the tbri during the retention interval. Recall could then be based upon the by-products of various rehearsal strategies or of time filling.

Few real life situations require immediate responses to signals because of the requirements of other

Table 2

Studies on Short-Term Memory of Time under the Method of Reproduction

Studies	Time Length	RI[a]		
		I[b]	U[c]	F[d]
Kowalski (1943)[e]	0.48 to 16.20 sec.			2.5 to 30.0 sec.
Chatterjea (1963)	2.0 to 32.0 sec.		10.33 to 10.83 sec.	
King (1965)	1.5 and 2.0 sec.		15.0 to 60.0 sec.	
King (1966)	0.5 to 3.0 sec.		60.0 sec.	
Richards and Livingston (1966)	2.0 to 16.0 sec.		2.0 to 25.0 sec.	
DuPreez (1967)	1.0 to 16.0 sec.	I	5.0 to 60.0 sec.	
McNutt and Melvin (1968)	1.0 to 29.0 sec.		1.0 to 29.0 sec.	
Vroon (1970)	3.0 sec.		2.0 to 120.0 sec.	
Hawkes, Worsham and Ray (1973)[f]	0.5 to 5.0 sec.		10.0 to 30.0 sec.	
Pöppel (1973)	2.0 sec.		0.4 to 50.0 sec.	
Hawkes, Ray and Hayes (1974)[g]	0.5 to 8.0 sec.		20.0 to 60.0 sec.	20.0 to 60.0 sec.

a RI = Retention Interval.
b I = Immediate.
c U = Unfilled.
d F = Filled.
e Filled task = color a geometrical design.
f Significant at the 0.05 level (mean judgments).
g Filled task = work on arithmetic problems.

duties. Yet if the memory for time is important, such delays and duties must not affect the memory for time unduly.

The following study was an investigation of the retention of temporal information where the to-be-remembered item consists of time estimations of short duration. The experimental protocol employed was the interference paradigm generally credited to Brown and Peterson, and popularized in the motor memory literature by Posner and Konick (1966). The paradigm was used to distinguish between memory loss due to: (a) length of time the tbri was stored and (b) the interference effects of irrelevant material which the subjects were required to attend to during the retention interval.

Method

Subjects

Twelve volunteer graduate students in physical education at the University of Alberta were used in this experiment.

Apparatus and Task

The apparatus and task were identical to the ones employed in Experiment 1 with the following additions.

Four of the six retention intervals described below were controlled by two decade interval timers

(Hunter 111-C and 100-C). These timers were connected to a tone generator (Eico 377), amplifier and speaker. When the circuit controlling the criterion time length had cycled through its pre-set time length, it started the timers controlling the retention interval. A continuous audible tone ensued for the full length of the retention interval, providing confirmation to the subjects of the passage of time. The subjects were asked to recall the to-be-remembered item immediately following cessation of the continuous tone.

Design

Six levels of retention: (a) immediate (IM), (b) self-paced (SP), (c) 15 seconds of rest (R.15), (d) 30 seconds of rest (R.30), (e) 15 seconds of interpolated activity (I.15), and (f) 30 seconds of interpolated activity (I.30), were used. These six levels of retention were combined factorially in a treatment by subjects' design with two levels of criterion time length; namely 1 and 4 seconds. Thirty trials were given for each of the 12 treatments. During the self-paced retention interval, the subjects were allowed to recall whenever they wished. The term time gap (TG) has been applied in the past to this intervening period between the presentation of a time length and the subjects' subsequent reproduction. This intervening period (Chatterjea, 1957)

differs from a pause or passive state in that the amount of time taken was left to the subjects. Hence, the TG seems to be a spontaneously consumed time which an individual apparently feels he needs before reproducing the time length (Chatterjea, 1963). The SP retention condition was utilized because several authors (Buckolz, 1972; Buckolz and Gervais, 1976; Buckolz and Guay, 1975; Chatterjea, 1963; Woodrow, 1930) used this retention condition with different presentation procedures and no attempt has been given to compare the results with the immediate retention condition. In those retention intervals requiring an interpolated activity, the subjects were asked to turn over a card from a small stack in front of them and commence counting backwards by three's from the number printed thereon (Peterson and Peterson, 1959).

<u>Procedure</u>

The subjects were given a number of trials to familiarize themselves with the experiment and the various retention demands. They attended four separate sessions, each approximately 70 minutes in length. The 12 treatment conditions were assigned to the subjects during the first three sessions, with the order of occurrence determined by a random balanced 12 X 12 Latin Square and with 4 treatments per session.

The instructions to the subjects concerned three points: (a) the subjects were asked to be as accurate as

possible, (b) the subjects were asked to express and demonstrate their understanding of the task, and (c) the subjects were asked not to use any time-aiding techniques at any time. The experimenter explained thoroughly what was meant by time-aiding techniques, giving examples of the various types.

One week following completion of the third session, the subjects returned and were given 30 trials of each criterion time length (one and four seconds) under the immediate and self-paced retention conditions. In this session, the subjects were asked to use mental counting as their cognitive strategy. The treatment order given to each subject was again varied according to a random balanced 4 X 4 Latin Square design repeated three times.

Data Analysis

The dependent variables used were: (a) absolute error (AE), (b) signed constant error (CE), (c) variable error (VE), and (d) average (mean) performance (AP).

A number of studies on the retention of time have used only the mean recall performance as their dependent measure (Hawkes, Ray and Hayes, 1974; Hawkes, Worsham and Ray, 1973; King, 1965, 1966; Kowalski, 1943; Vroon, 1970). This dependent variable termed mean reproduction is generally considered the poorer of a number

of associated measures (Schutz, 1974; Schutz and Roy, 1973) and cannot supply the reader with more than a simple magnitude estimate of memory loss. The absolute magnitude measure touches briefly on the concept of accuracy and can say nothing at all about precision (variability). More is to be gained with the utilization of dependent variables such as signed constant error, absolute error and variable error (Schutz and Roy, 1973). These variables have been used in the motor short-term memory literature to describe the effects of retention intervals and interference factors. Consequently, on account of the common acceptance of these statistics as valid measures of performance error, they will be used in the present studies.

Results

First Three Sessions

Raw Data

For each subject and each level of the two factors (time lengths and retention intervals), the 30 trials were divided into 6 blocks of 5 trials each. Twelve one-way analyses of variance (blocks by subjects) were calculated for average time estimation, one for each treatment condition. The blocks' main effect was not significant ($p > .05$) for all treatment conditions. The effect was qualified stationary or fixed and the 30 trials for each subject were reduced to a simple mean.

Time Length

The mean (30 trials) raw time-keeping scores calculated for each treatment condition and each subject was termed average performance. The subjects were able to maintain their estimates of one and four seconds as distinct events over experimental conditions, F (1,11) = 185.41, $p < .01$. This suggests that when errors arose they were not due to the subjects confusing the two time lengths either perceptually or in memory. The interaction between time length and retention interval for average performance was not significant ($p > .05$).

The main effect of time length was found to be significant for both absolute error, F (1,11) = 73.09, $p < .01$, and variable error, F (1,11) = 130.51, $p < .01$. The subjects produced larger errors and were more variable in their estimates of the four seconds time length as compared to the one second time length. However, interactions between time length and retention interval occurred for absolute error, F (5,55) = 3.69, $p < .01$, and variable error, F (5,55) = 5.78, $p < .01$. The interaction effects which were almost totally due to the four seconds time length when held in memory for 15 seconds or more, can be seen in Figures 5 and 6.

The subjects did not show any significantly consistent directional bias in their estimates of either one or four seconds. The method of providing subjects with at least 30 trials of one time length before presenting them

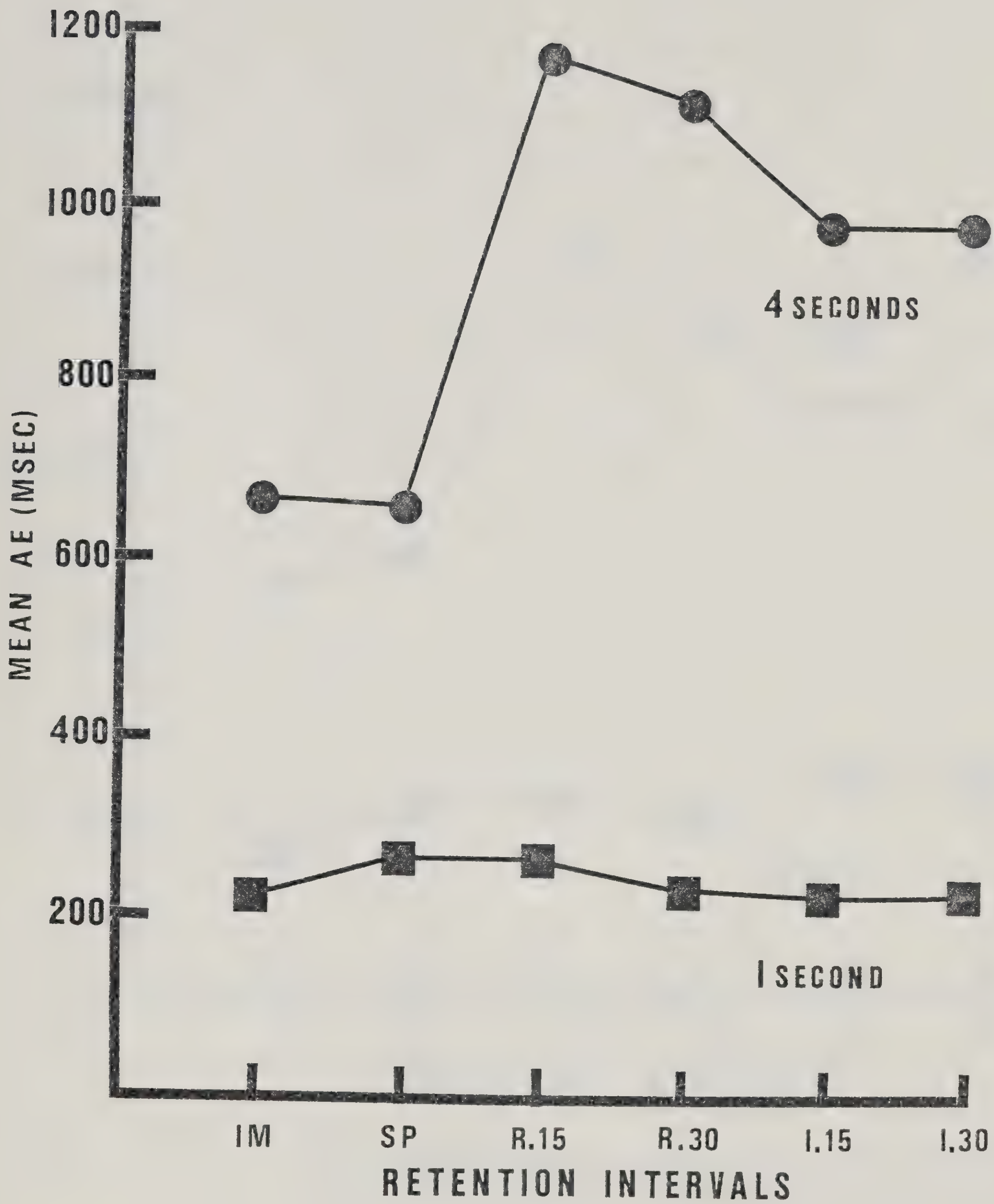


Figure 5 Mean absolute error (AE) for the 1 and 4 seconds time lengths as a function of the retention intervals (IM = immediate; SP = self-paced; R.15 = 15 seconds of rest; R.30 = 30 seconds of rest; I.15 = 15 seconds of interpolated activity; I.30 = 30 seconds of interpolated activity)

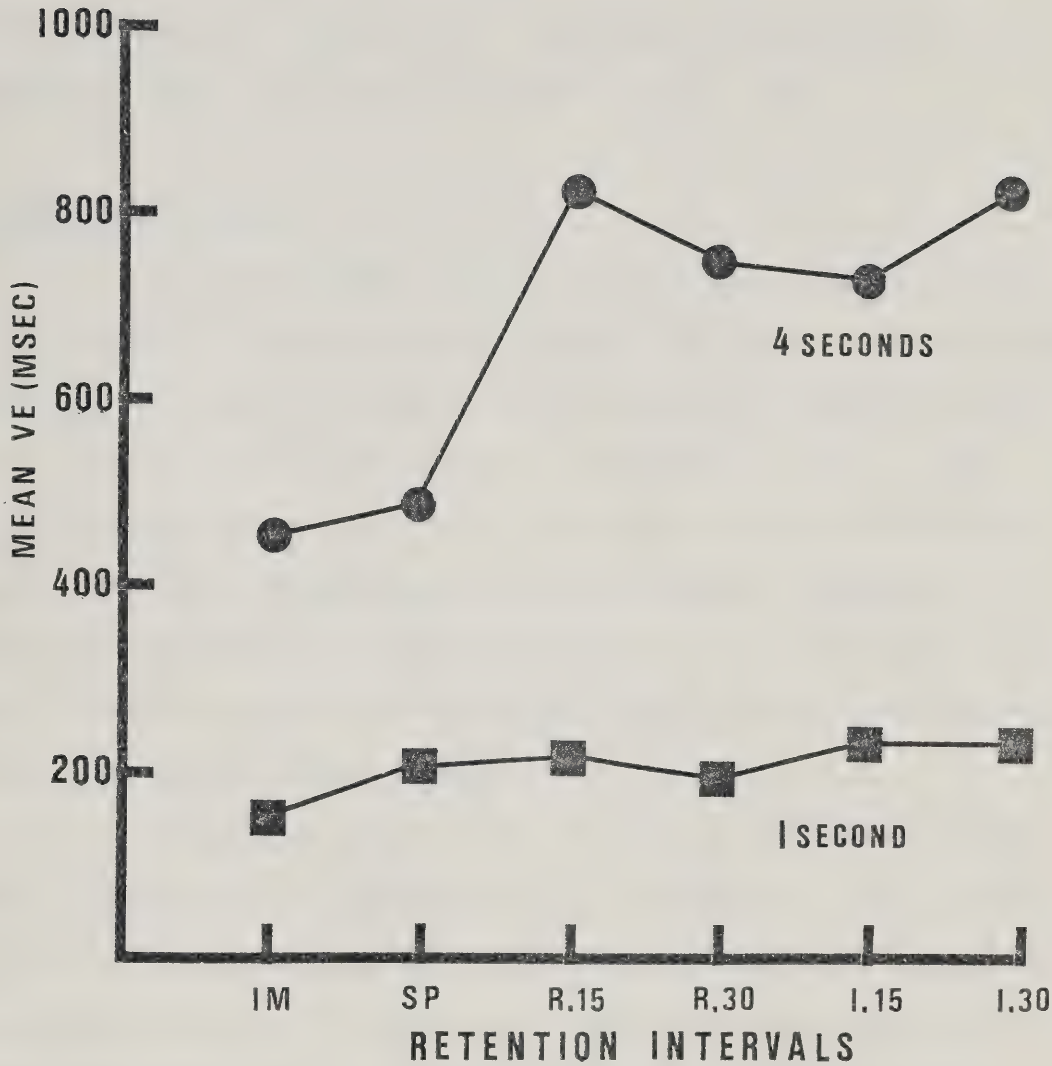


Figure 6 Mean variable error (VE) for the 1 and 4 seconds time lengths as a function of the retention intervals (IM = immediate; SP = self-paced; R.15 = 15 seconds of rest; R.30 = 30 seconds of rest; I.15 = 15 seconds of interpolated activity; I.30 = 30 seconds of interpolated activity)

with 30 trials of the second very likely eliminated the usual development of a central tendency or range effect. The time length by retention interval interaction for constant error was not significant ($p > .05$).

Retention Interval

A significant effect, F (5,55) = 3.47, $p < .01$, was found for absolute error across the retention intervals. Because of the significant time length by retention interval interaction noted earlier, a Scheffé's test on the simple main effect was run. The significant differences were that the immediate and the self-paced retention intervals resulted in smaller errors ($p < .05$) than the 15 and 30 second retention intervals (filled and unfilled) for the four seconds time length.

Variable error scores analyzed across the retention intervals also resulted in a significant main effect, F (5,55) = 8.16, $p < .01$. The significant time length by retention interval interaction reported above resulted in the calculation of a second simple main effect using a Scheffé's test. Significant differences were found between the following contrasts for the four seconds time length only: immediate and self-paced retention intervals were significantly less variable than all other retention intervals ($p < .05$).

Signed constant error scores did not produce significant main effect across retention intervals

(p > .05). The lack of significance can again be attributed in part to the procedures used. Those procedures were devised to suppress the development of central tendency effect.

The F ratio for retention interval obtained from average performance measurements was not significant (p > .05). The various mean error scores for each condition of time length and retention interval are summarized in Table 3.

Fourth Session

The 12 treatment conditions were completed for all subjects in three testing sessions. A fourth session was added in which the subjects were asked to use mental counting as their cognitive strategy. The data gained from this session was used as comparison data against some of the conscious time estimation conditions. This comparison was used to ensure that the subjects had actually refrained from using some sort of time-aiding technique during the first three sessions.

Analyses of variance were carried out on absolute error, constant error, variable error and average performance. Two levels of cognitive strategies: (a) mental counting, and (b) conscious time estimation were used. These two levels of strategies were combined factorially in a treatment by subjects' design with two levels of criterion time length: (a) one second, and (b) four

Table 3

Mean VE, AE, AP and CE in Milliseconds for Time Length and Retention Interval

Time Length	Retention Interval[a] IM	SP	R.15	R.30	I.15	I.30
			Variable Error (VE)			
1 second	172	202	218	193	226	238
4 seconds	456	485	827	750	729	824
			Absolute Error (AE)			
1 second	226	272	268	235	231	242
4 seconds	671	661	1173	1125	990	991
			Average Performance (AP)			
1 second	1071	1225	953	981	1085	1058
4 seconds	3851	3853	4073	3554	3899	4243
			Constant Error (CE)			
1 second	71	225	- 47	- 19	85	58
4 seconds	- 149	- 147	73	- 447	- 101	243

[a] IM = immediate
SP = self-paced
R.15 = 15 seconds of rest
R.30 = 30 seconds of rest
I.15 = 15 seconds of interpolated activity
I.30 = 30 seconds of interpolated activity

seconds; and two levels of retention interval: (a) immediate, and (b) self-paced.

Raw Data

All raw time estimate data gained in the fourth session for each treatment condition and each subject were visually inspected. In only a few cases did the data show a lengthening or shortening effect. Again the 30 trials for each subject were reduced to a simple mean.

Time Length

The subjects were again able to maintain their estimates of one and four seconds as distinct events over experimental conditions, $F\ (1,11) = 1133.82$, $p < .01$.

A significant effect of time length was found for both absolute error, $F\ (1,11) = 53.38$, $p < .01$, and variable error, $F\ (1,11) = 109.44$, $p < .01$. The subjects produced larger errors and were more variable in their estimates of four seconds as compared to their estimates of the one second time length. However, interactions between time length and cognitive strategy occurred for absolute error, $F\ (1,11) = 15.03$, $p < .01$, and for variable error, $F\ (1,11) = 26.33$, $p < .01$. The interaction effects which were almost totally due to the four seconds time length when the subjects were asked to use mental counting as their cognitive strategy, can be seen in Figures 7 and 8.

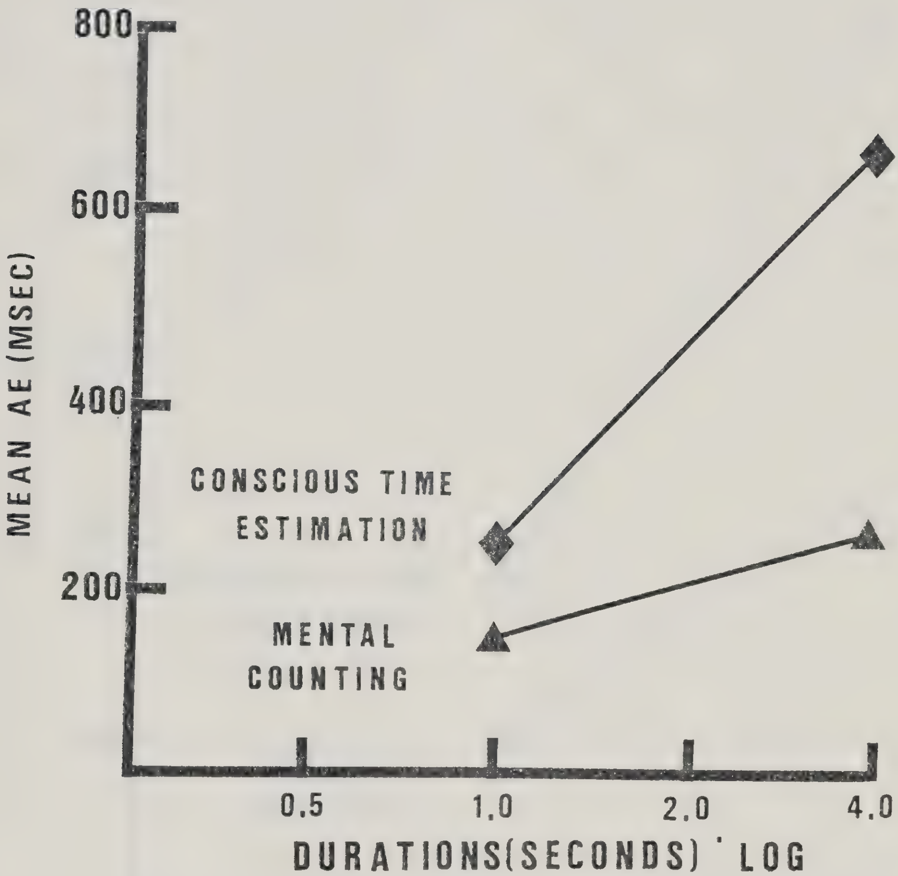


Figure 7 Mean absolute error (AE) for mental counting and conscious time estimation cognitive strategies as a function of 1 and 4 seconds time lengths

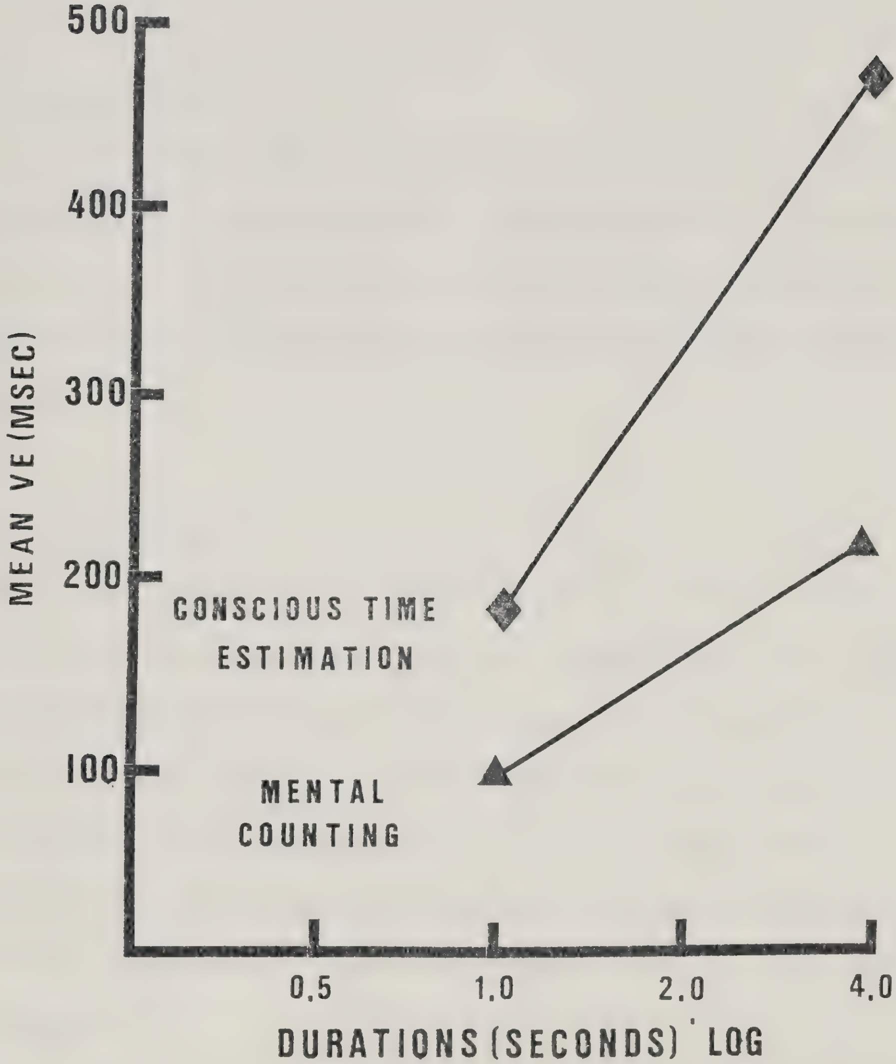


Figure 8 Mean variable error (VE) for mental counting and conscious time estimation cognitive strategies as a function of 1 and 4 seconds time lengths

The main effect of time length was significant for constant error, F (1,11) = 10.15, $p < .01$. Subjects overestimated the one second time length and underestimated the four seconds time length.

Retention Interval

The main effect of retention interval was only significant for variable error measurements, F (1,11) = 8.5, $p < .05$. Subjects were more variable under the self-paced retention interval than the immediate retention interval.

Cognitive Strategy

A significant effect, F (1,11) = 36.74, $p < .01$, of cognitive strategy was found for absolute error scores. Because of the significant time length by cognitive strategy interaction noted earlier a Scheffé's test ($p < .05$) on the simple main effect was run. The significant difference was that mental counting resulted in smaller errors than conscious time estimation for the four seconds time length.

Variable error scores for cognitive strategy also resulted in a significant main effect, F (1,11) = 46.33, $p < .01$. The significant time length by cognitive strategy interaction reported above resulted in the calculation of a second simple main effect using Scheffé's test.

Significant differences were found between mental counting and conscious time estimation for the 1 and 4 seconds time lengths ($p < .05$). Subjects were less variable under mental counting for both time lengths. The F ratio for cognitive strategy obtained from constant error and average performance measurements were not significant ($p > .05$).

No other significant interactions were observed in any of the four dependent measures. The means of the various error scores for each level of cognitive strategy, time length, and retention interval are summarized in Table 4.

Discussion

First Three Sessions

Time Length and Retention Interval

The significant main effect of time length along with its significant interaction with retention interval for both absolute and variable error, suggest that subjects retain time lengths of one and four seconds differently. When subjects hold a criterion time of four seconds in memory for a period of 15 to 30 seconds of rest, they become less accurate and more variable than if they recall the item: (a) immediately, (b) at their own pace, or if the item to be remembered is only one second long. When a non-structural interpolated task (backward

Table 4

Mean VE, AE, AP and CE in Milliseconds for Cognitive Strategy, Time Length and Retention Interval

	Cognitive Strategy			
	Conscious Time Estimation		Mental Counting	
	Retention Interval			
Time Length	Immediate	Self-paced	Immediate	Self-paced
	Variable Error (VE)			
1 second	172	202	90	106
4 seconds	456	485	204	235
	Absolute Error (AE)			
1 second	226	272	138	148
4 seconds	671	661	280	239
	Average Performance (AP)			
1 second	1071	1225	1114	1116
4 seconds	3851	3853	3825	3960
	Constant Error (CE)			
1 second	71	225	114	116
4 seconds	- 149	- 147	- 175	- 40

counting) was required during the retention interval, its effect was similar to the results obtained under an unfilled retention interval for both durations.

Similarities between the results of this investigation and those obtained for motor short-term memory were the following: (a) the reproduction of a one second time length under an unfilled retention interval was quite similar to the reproduction of movement information when location was the only reliable cue (Alain, 1974; Dukes, 1970; Hughes, 1969; Keele and Ells, 1972; Laabs, 1971; Wilberg, 1969), (b) the reproduction of a four seconds time length under an unfilled retention interval was in line with the reproduction of movement information when distance was the only reliable cue, information of this type seems to spontaneously decay (Adams and Dijkstra, 1966; Laabs, 1971; Posner, 1967; Posner and Konick, 1966), and (c) the reproduction of a one or four seconds time length under a filled retention interval (verbal interpolated task) was quite like the results of Posner (1967), Posner and Konick (1966) and Williams, Beaver, Spence and Rundell (1969) who found that no difference existed between an unfilled and a filled retention interval for movement information.

A theory of temporal memory has not yet been proposed which could account for these results. One could speculate that time lengths of four seconds or more exceed immediate memory span and suffer accordingly.

Such a speculation would indicate that there is a time length constraint on temporal short-term memory (STM). When exceeded, the memory for the particular time length is degraded. The concept of a memory buffer with a fixed size may be a weak but near analogy. In this instance, the maximum length of any given temporal event, as well as the total number of to-be-remembered items may be limited. While we do not have any evidence supporting a specific time length event capacity for temporal STM, the data suggests that there could be a maximum temporal memory span for any specific time length event.

The results of the analyses of the three error scores are equivocal in their support of the single and/or the dual memory trace theories. The retention characteristics for the one second time length are in line with the single trace model, while the increased variability and decreased accuracy of the four seconds time length across retention conditions supports the dual trace notion.

Some verbalization undoubtedly is involved. The introspective reports of the subjects obtained after the experiment indicate in all conditions the use of crude verbal labels, such as very short, short, 3 seconds, and so on. It may be possible that the time lengths are encoded verbally as well.

Fourth Session

Time Length and Cognitive Strategy

The significant main effect of time length along with its significant interaction with cognitive strategy for both absolute and variable errors suggest that subjects were able to use a cognitive strategy, such as mental counting, as an effective method of reducing errors in the recall of the to-be-remembered item. Subjects were again more accurate when allowed to use mental counting to keep track of time for the four seconds time length. A similar finding was observed in Experiment 1. The mental counting cognitive strategy resulted in less variability than conscious time estimation for both durations. Such a result was evident for the four seconds time length but not for the one second time length in Experiment 1. The reason for a significant difference for the one second time length of the present study was due to the subjects' performance under conscious time estimation. These estimations were worse than the ones obtained by the subjects of Experiment 1 for the identical cognitive strategy. It would appear then that the imposition of some form of discreteness (by means of mental counting) on the continuous nature of time results in more accurate and less variable performance. The data obtained during that fourth session provide evidence that the subjects actually re-

frained from using some sort of time-aiding techniques during the course of the first three sessions.

Although a few answers concerning temporal short-term memory under variations of conscious time estimation were provided in Experiment 2, very little is known about the length of time a to-be-remembered item may be stored. Consequently, the aim of Experiment 3 was to determine the period of time that a particular time length could be stored in memory. In order to achieve that purpose, four time lengths and five retention intervals were used. Subjects were again asked to consciously estimate time.

Experiment 3

Conscious Time Estimation

and

Retention of Time over Unfilled Temporal Delays

On account of the unfilled temporal delays (15 and 30 seconds) used in Experiment 2, one might question at what particular delay interval does the to-be-remembered item (tbri) become less accurate and more variable. Also one might ask if that particular delay interval is the same for all time lengths when significant results are obtained. In order to answer these questions the following study investigated the retention of time where the tbri consisted of short time lengths under very short unfilled delay intervals.

Method

Subjects

Twenty volunteer undergraduate and graduate students in physical education at the University of Alberta were used in this experiment.

Apparatus and Task

The apparatus and the task were the same as were used in Experiment 2 for unfilled retention intervals.

Design

Five levels of retention: (a) immediate (IM), (b) 2 seconds of rest (R.2), (c) 4 seconds of rest (R.4), (d) 8 seconds of rest (R.8), and (e) 16 seconds of rest (R.16) were used. These five levels of retention were combined factorially in a treatment by subjects' design with four levels of criterion time length; namely 1, 2, 4 and 8 seconds. Twenty trials were given for each of the 20 treatments.

Procedure

The subjects were given a number of trials to familiarize themselves with the equipment and the various retention demands. They attended four separate sessions of approximately 40 minutes each in length with 5

treatments per session. A random 4 X 4 Latin Square for time lengths was used with 5 subjects per row. One length of time was used per session for each subject. Another random 5 X 5 Latin Square for retention conditions was used with each row repeated under each time length in combination with one subject of each row of the time length 4 X 4 Latin Square. The instructions to the subjects were the same as Experiment 2.

Data Analysis

The error scores examined were similar to those utilized in the previous experiments.

Results

Raw Data

For each subject and each level of the two factors (time length and retention interval), the 20 trials were divided into 2 blocks of 10 trials each. Twenty one-way analyses of variance (blocks by subjects) were calculated for the average performance dependent measure, one for each treatment condition. The blocks' main effect was not significant ($p > .05$) for all treatment conditions. Therefore, the 20 trials for each subject were reduced to a simple mean.

Time Length

A significant effect of time length was found for average performance, F (3,57) = 262.93, $p < .01$. A post hoc analysis using the Scheffé's test ($p < .05$) indicated that the four time lengths were significantly distinct events, one from the other. This suggests that when errors arose they were not due to the subjects confusing the four time lengths either perceptually or in memory. An interaction between time length and retention interval occurred for average performance, F (12,228) = 5.57, $p < .01$. As illustrated in Figure 9, the interaction effect was almost totally due to the eight seconds time length when held in memory for 8 seconds or more.

A significant effect of time length was also found for absolute error (unsigned error), F (3,57) = 61.37, $p < .01$. Further analysis by the Scheffé's test ($p < .05$) demonstrated that subjects produced significantly larger errors for the eight seconds time length as compared to the one, two and four seconds time lengths. Meaningful differences were also obtained for the four seconds time length compared to the one and two seconds time lengths. The interaction between time length and retention interval for absolute error did not reach the conventional level of significance.

For variable error scores (the standard deviation of the constant error or of the average performance), the

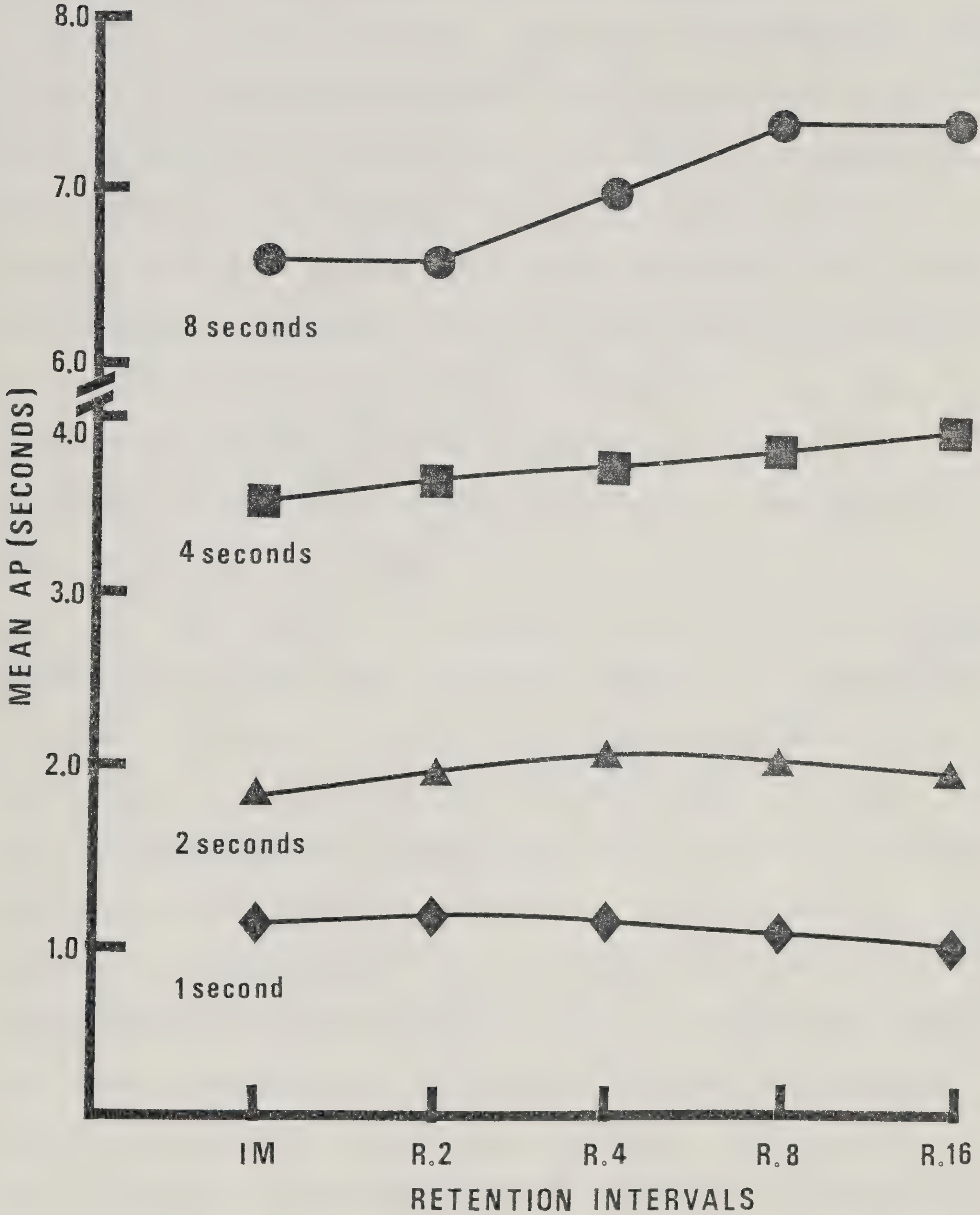


Figure 9 Mean average performance (AP) for the 1, 2, 4 and 8 seconds time lengths as a function of the retention intervals (IM = immediate; R.2 = 2 seconds of rest; R.4 = 4 seconds of rest; R.8 = 8 seconds of rest; R.16 = 16 seconds of rest)

main effect of time length was again significant, $F\ (3,57) = 127.96$, $p < .01$. Employing the Scheffé's test ($p < .05$) it was demonstrated that the subjects were significantly more variable as time length increased with the exception that the variability between the one and two seconds time lengths was nearly identical. An interaction between time length and retention interval occurred for variable error, $F\ (12,228) = 5.52$, $p < .01$. The interaction effect was almost totally due to the four and eight seconds time lengths when held in memory for 8 seconds or more (see Figure 10).

With respect to signed constant error (algebraic error), time length ~~was~~ once again found to be significant, $F\ (3,57) = 9.03$, $p < .01$. A post hoc analysis using the Scheffé's test ($p < .05$) indicated that the one, two and four seconds time lengths were significantly different than the eight seconds time length. Subjects had a tendency to overestimate the one second time length and to underestimate the two, four and eight seconds time lengths. There was a significant interaction between time length and retention interval for constant error, $F\ (12,228) = 5.59$, $p < .01$. As illustrated in Figure 11, this interaction effect was almost totally due to the eight seconds time length when held in memory for 8 seconds or more.

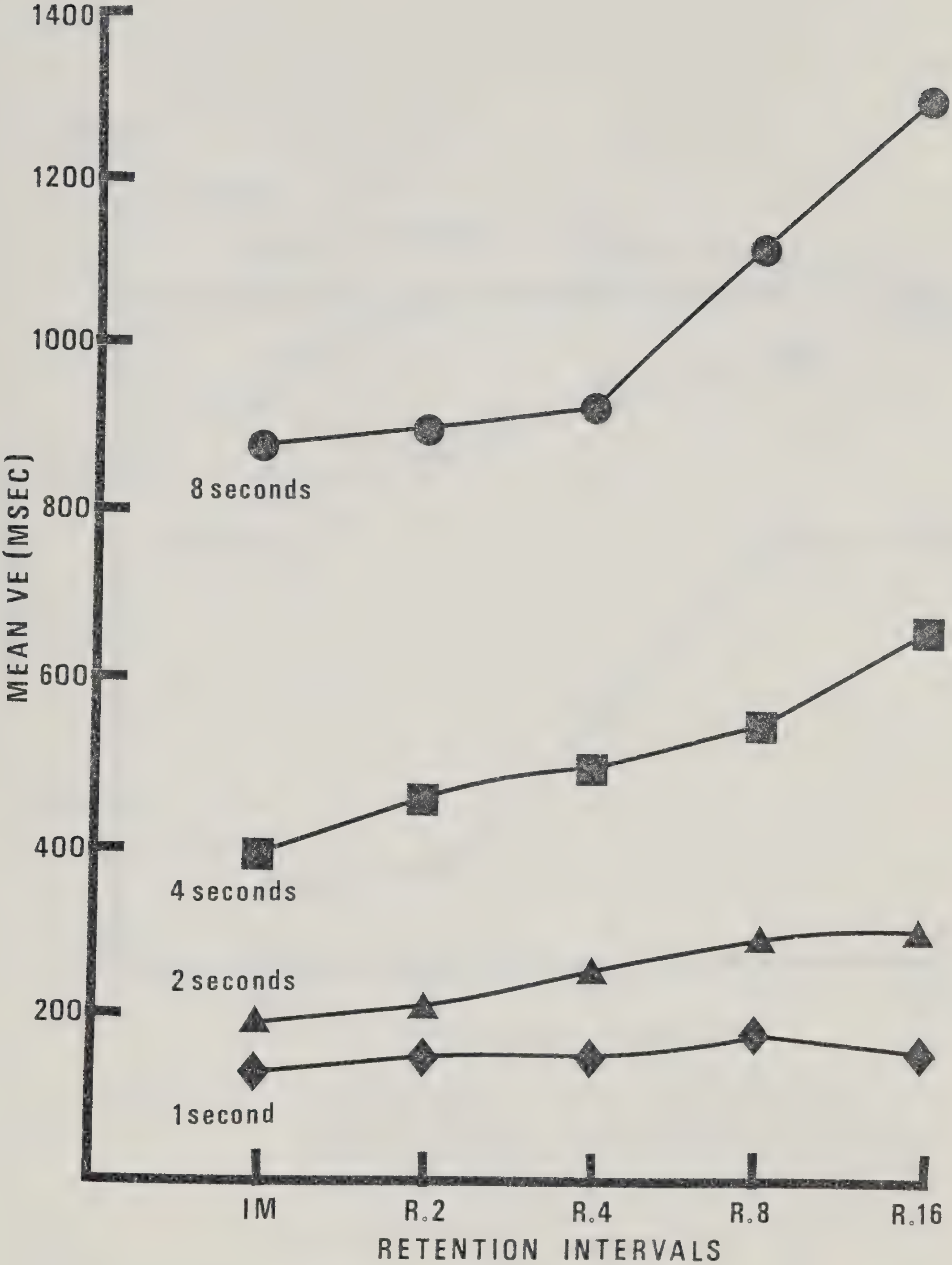


Figure 10 Mean variable error (VE) for the 1, 2, 4 and 8 seconds time lengths as a function of the retention intervals (IM = immediate; R.2 = 2 seconds of rest; R.4 = 4 seconds of rest; R.8 = 8 seconds of rest; R.16 = 16 seconds of rest)

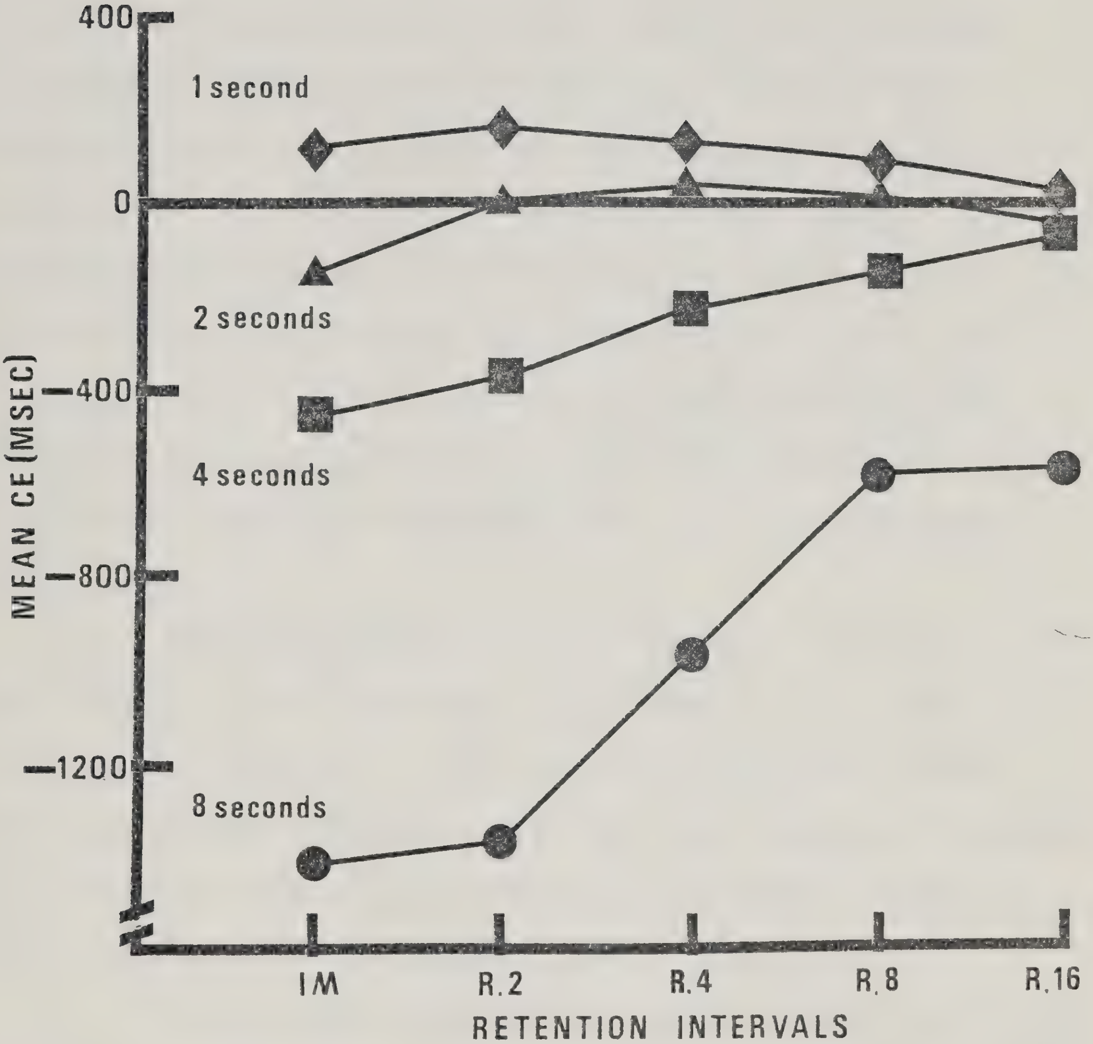


Figure 11 Mean constant error (CE) for the 1, 2, 4 and 8 seconds time lengths as a function of the retention intervals (IM = immediate; R.2 = 2 seconds of rest; R.4 = 4 seconds of rest; R.8 = 8 seconds of rest; R.16 = 16 seconds of rest)

Retention Interval

A significant effect, F (4,76) = 5.3, $p < .01$, was found for average performance across the retention intervals. Because of the significant time length by retention interval interaction noted earlier, a Scheffé's test ($p < .05$) was run on the simple main effect. The immediate and the two seconds retention intervals were found to be significantly different from the 8 and 16 seconds retention intervals for the eight seconds time length. Average performance scores were greater for the latter two retention intervals under the eight seconds time length.

The main effect for AE retention intervals was also found to be significant, F (4,76) = 3.40, $p < .05$. A Scheffé's test ($p < .05$) was run on the main effect. The significant difference was that the immediate retention interval was more accurate than the 16 seconds retention interval for all time lengths (see Figure 12).

A significant effect, F (4,76) = 22.50, $p < .01$, was again found for variable error scores across the retention intervals. Because of the significant time length by retention interval interaction noted earlier, a Scheffé's test ($p < .05$) was run on the simple main effect. A number of significant contrasts were obtained. The immediate retention interval was less variable than the 16 seconds retention interval for the four seconds time length. In addition, the immediate and 2 seconds retention

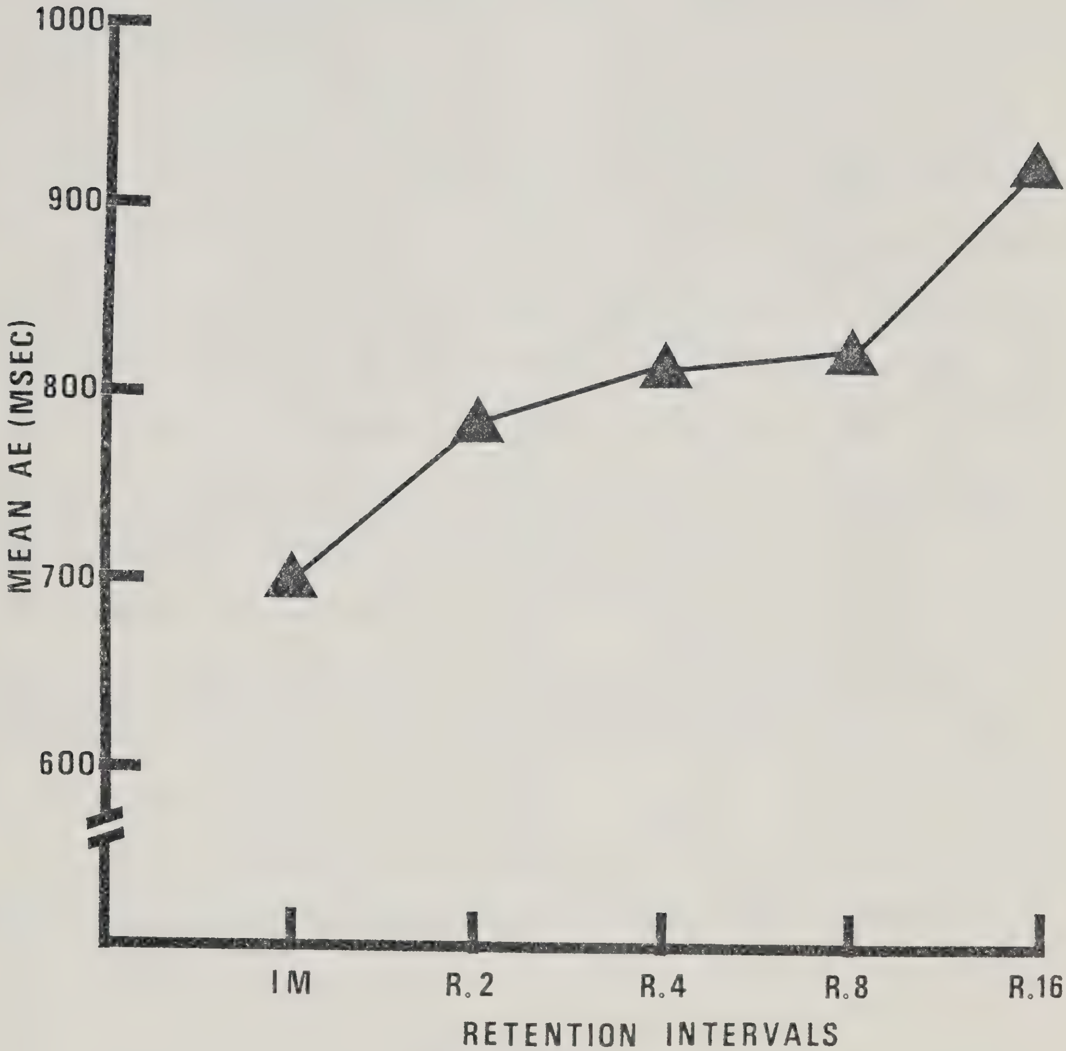


Figure 12 Mean absolute error (AE) for subjects recall performance of time lengths as a function of retention intervals (IM = immediate; R.2 = 2 seconds of rest; R.4 = 4 seconds of rest; R.8 = 8 seconds of rest; R.16 = 16 seconds of rest)

intervals were less variable than the 8 and 16 seconds retention intervals for the eight seconds time length. Finally, the 4 seconds retention interval was less variable than the 16 seconds retention interval for the eight seconds time length.

Finally, a significant effect, $\underline{F}$ (4,76) = 5.32, $\underline{p} < .01$, was found for constant error measurements across the retention intervals. Because of the significant time length by retention interval interaction noted earlier, a Scheffé's test ($\underline{p} < .05$) was run on the simple mean effect. The significant differences were that the immediate and 2 seconds retention intervals were less accurate than the 8 and 16 seconds retention intervals for the eight seconds time length. That is, under the first two levels of retention interval subjects underestimate the 8 seconds time length more than they do under the latter two retention interval conditions.

The various error scores for each level of time length and retention interval are summarized in Table 5.

Discussion

Time Length and Retention Interval

On the one hand the significant effects of time length and retention interval along with a non-significant interaction between the above two factors for absolute

Table 5

Mean VE, AE, AP and CE in Milliseconds for Time Length and Retention Interval

Time Length	Retention Interval[a]	Dependent Measure[b] VE	AE	AP	CE
1 second	IM	131	184	1106	106
	R.2	149	213	1166	166
	R.4	153	248	1149	149
	R.8	177	249	1094	94
	R.16	159	241	1049	49
2 seconds	IM	186	261	1841	- 159
	R.2	212	318	1990	- 10
	R.4	254	375	2045	45
	R.8	284	455	2052	52
	R.16	286	434	1965	- 35
4 seconds	IM	393	664	3537	- 463
	R.2	457	746	3627	- 373
	R.4	486	882	3768	- 232
	R.8	544	906	3854	- 146
	R.16	659	1006	3954	- 46
8 seconds	IM	866	1665	6608	-1392
	R.2	904	1750	6624	-1376
	R.4	932	1747	7039	- 961
	R.8	1118	1671	7419	- 581
	R.16	1292	1991	7437	- 563

[a] IM = Immediate
R.2 = 2 seconds of rest
R.4 = 4 seconds of rest
R.8 = 8 seconds of rest
R.16= 16 seconds of rest

[b] VE = variable error
AE = absolute error
AP = average performance
CE = constant error

error scores, suggest that subjects retain time lengths of one, two, four and eight seconds in the same way. When subjects hold criterion times of one, two, four or eight seconds in memory for a period of 16 seconds, they become less accurate than if they recall the item immediately. It can be concluded that subjects reproduced time lengths of 1 to 8 seconds with less accuracy after a short period of time (16 seconds) than immediately even when there was nothing restraining the subjects from devoting their attention to the criterion material. These results are partly in conformance with those of Experiment 2. In the latter investigation, for the one second time length, it was found that the subjects reproduced as well after 30 seconds as immediately. The data for the four seconds time length obtained in Experiment 2 are in agreement with the present study.

On the other hand the significant effects of time length and retention interval along with a significant interaction between time length and retention interval for variable error measurements, suggest that subjects retain time lengths of one, two, four and eight seconds differently. When subjects hold a criterion time of eight seconds in memory for a period of 8 or 16 seconds, they become more variable than if they recall the item immediately or after 2 seconds of rest. For the subjects holding the four seconds to-be-remembered item for a period of 16 seconds,

more variance is denoted than if they recall the item immediately. Finally, when one and two seconds time lengths are used, no evidence of significant variability is present. Similar findings for the one and four seconds time lengths of the present study were obtained in Experiment 2 for the variable error dependent measure.

Similarities between the results of this investigation in terms of variability and those obtained for motor short-term memory are the following: (a) the reproduction of a one or two seconds time length under an unfilled retention interval was quite similar to the reproduction of movement information when location was the only reliable cue (Alain, 1974; Keele and Ells, 1972; Laabs, 1973), and (b) the reproduction of a four or eight seconds time length under an unfilled retention interval was quite similar to the reproduction of movement information when distance was the only reliable cue; information of this type seems to spontaneously decay (Laabs, 1973).

A theory of temporal short-term memory was proposed in Experiment 2 which speculated that time lengths of four seconds or more exceed immediate memory span and suffer accordingly. The present results support the notion of a time length constraint on temporal short-term memory. The eight seconds time length degraded or faded sooner than the four seconds time length across the unfilled retention intervals.

The results of the analysis of the variable error scores are equivocal in their support of the single trace and/or the dual memory trace theories. The retention characteristics for the one and two seconds time lengths are in line with the single trace model, while the increased variability of the four and eight seconds time lengths supports the dual trace notion. As in Experiment 2, some verbalization was involved and crude verbal labels were employed.

On the basis of Experiment 1, conscious time estimation and mental counting were the two cognitive strategies chosen to be examined in further detail in terms of short-term retention characteristics. Experiments 2 and 3 provided a few answers on the short-term retention of time when subjects were under a conscious time estimation cognitive strategy. The purposes of Experiment 4 were to investigate the short-term retention of time when subjects were under a mental counting cognitive strategy and to determine if the short-term retention of time under such a cognitive strategy was different from that under conscious time estimation.

Experiment 4
Mental Counting
and
Retention of Time

The retention of to-be-remembered temporal items may depend upon the manner and the depth to which those items are encoded (Lockhart, Craik and Jacoby, 1976). Experiments 2 and 3 provided results on the retention of time when subjects were under the performance mode of conscious time estimation. Absolutely nothing is known about the retention of time when subjects are asked to use a time-aiding technique. Such a performance mode (time-aiding technique) may yield different retention characteristics of the to-be-remembered item.

The following study was an investigation of the retention of temporal information where the to-be-remembered item (tbri) consists of time estimation of short duration. The experimental protocol employed was again the Brown and Peterson interference paradigm. This paradigm was used to distinguish between memory loss due to: (a) the length of time the tbri was stored, and (b) the interference effect of irrelevant material which the subjects were required to attend to during the retention interval. The major distinction between the present study and Experiment 2 was that subjects in the present study were able to use a time-aiding technique. The experimenter-defined time-aiding technique employed by the subjects was a mental counting cognitive strategy.

Method

Subjects

Twelve volunteer graduate students in physical education at the University of Alberta were used in this experiment.

Apparatus, Task, Design, Procedure and Data Analysis

The apparatus, the task, the design, the procedure and the dependent variables were the same as those described and used in Experiment 2 (first three sessions) with the following change in the third instruction given to the subjects (instruction-c in the procedure): (c) the subjects were asked to use a mental counting cognitive strategy. The experimenter explained thoroughly what was meant by this term.

Results

Raw Data

For each subject and each level of the two factors (time lengths and retention intervals), the 30 trials were divided into 6 blocks of 5 trials each. Twelve one-way analyses of variance (blocks by subjects) were calculated for average time estimations, one for each treatment condition. The blocks' main effect was

not significant ($p > .05$) for all treatment conditions. The effect was qualified as stationary or fixed and the 30 trials for each subject were reduced to a simple mean.

Time Length

The mean (30 trials) raw score was calculated for each treatment condition and each subject's average performance was termed. The subjects were able to maintain their estimates of one and four seconds as distinct events over all experimental conditions, F (1,11) = 9831.75, $p < .01$. This suggests that when some errors arose they were not due to the subjects confusing the two time lengths either perceptually or in memory. The interaction between time length and retention interval for average performance was not significant ($p > .05$).

A significant main effect of time length, F (1,11) = 49.86, $p < .01$, was found for the dependent variable, absolute error. The subjects produced larger errors in their estimates of four seconds than they did when estimating the one second time lengths. The time length by retention interval interaction for absolute error was not significant ($p > .05$).

Variable error scores analyzed across the time lengths also resulted in a significant main effect, F (1,11) = 91.50, $p < .01$. The subjects were more variable in the four seconds than the one second condition.

The interaction between time length and retention interval for variable error was also not significant (*p* $>$ .05).

With respect to constant error scores, the main effect of time length was significant (F (1,11) = 33.43, *p* $<$ .01. The subjects demonstrated a consistent directional bias in their estimates of the one second (overestimators) and the four seconds (underestimators) time lengths. The interaction between time length and retention interval for signed constant error was not significant (*p* $>$ .05).

Retention Interval

A significant effect, *F* (5,55) = 7.04, *p* $<$ .01, was found for variable error measurements across the retention intervals. A Scheffé's test revealed significant differences between the immediate condition and all but one of the other retention interval lengths. Specifically, subjects' estimates of time in the immediate condition were less variable than those in the other retention interval conditions with the exception of the self-paced condition (see Figure 13).

The retention interval main effect was not significant (*p* $>$ .05) for absolute error, constant error and average performance. The means of the various error scores for each time length and retention interval are summarized in Table 6.

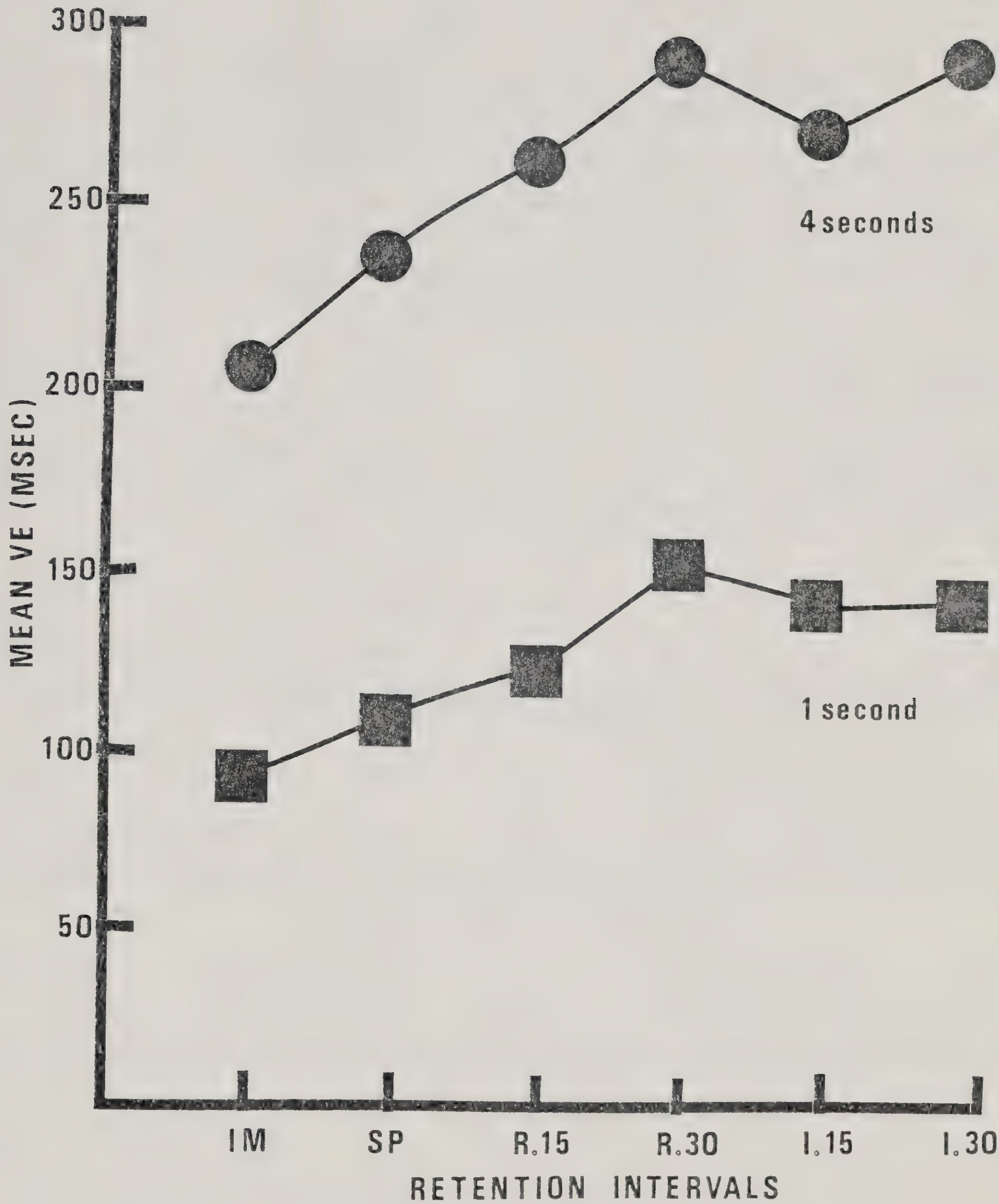


Figure 13 Mean variable error (VE) for the 1 and 4 seconds time lengths as a function of the retention intervals (IM = immediate; SP = self-paced; R.15 = 15 seconds of rest; R.30 = 30 seconds of rest; I.15 = 15 seconds of interpolated activity; I.30 = 30 seconds of interpolated activity)

Table 6

Mean VE, AE, AP and CE in Milliseconds for Time Length and Retention Interval

Time Length	IM	SP	R.15	R.30	I.15	I.30
			Retention Interval[a]			
			Variable Error (VE)			
1 second	90	106	121	148	141	140
1 second[b]	172	202	218	193	226	238
4 seconds	204	235	262	288	270	287
4 seconds[b]	456	485	827	750	729	824
			Absolute Error (AE)			
1 second	138	148	131	157	158	185
4 seconds	280	239	325	306	292	301
			Average Performance (AP)			
1 second	1114	1116	1019	1060	1101	1071
4 seconds	3825	3960	3830	3927	3985	3955
			Constant Error (CE)			
1 second	114	116	19	59	101	71
4 seconds	- 175	- 40	- 170	- 73	- 15	- 38

[a] IM = immediate
SP = self-paced
R.15 = 15 seconds of rest
R.30 = 30 seconds of rest
I.15 = 15 seconds of interpolated activity
I.30 = 30 seconds of interpolated activity

[b] Variable error scores obtained in Experiment 2 under conscious time estimation cognitive strategy.

Discussion

The significant main effects of time length and retention interval along with their non-significant interaction for variable error scores, suggest that subjects retain time lengths of one and four seconds in a similar fashion. When subjects held criterion times of one or four seconds in memory for a period of 15 or 30 seconds with or without interpolated activity, they were more variable than if they recalled the item immediately or at their own pace.

All subjects reported that the act of mental counting was the cognitive strategy which they had used. When questioned further, the subjects explained that when faced with the task of reproducing a time length, they subdivided the interval into a sequence of short durations (subjective time units) by counting rhythmically "one, two, three ...". The suggestion is that subjects are less variable when allowed to use a subdivision type of strategy along with counting. The finding coincides with the results of Experiment 2 for the same time lengths and retention intervals under a conscious time estimation cognitive strategy (see Table 6).

The memory of a time length under a mental counting cognitive strategy implies that the subjects retain: (a) a 'number' of subjective time units, and

(b) the 'length' of the subjective time unit (counting rate). The retrieval of the 'number' of subjective time units by the subjects is easily satisfied and results in a decrease in variability across the retention intervals. There is no evidence that the 'length' of the subjective time unit is remembered (Vroon, 1976). According to the present data, it seems that after an unfilled or filled retention interval of 15 seconds or more, the length of the subjective time unit is retrieved with more variability by the subjects.

Differences in terms of variability between the results of this investigation under a mental counting cognitive strategy and those obtained in Experiment 2 under a conscious time estimation cognitive strategy were the following: (a) when subjects reproduced a four seconds time length under mental counting or conscious time estimation, they followed the same retention characteristics (subjects were more variable after an unfilled or filled retention interval of 15 seconds or more than was the case when they reproduced immediately or at their own pace). There was less variability under mental counting than under conscious time estimation for all retention conditions; and (b) when subjects reproduced a one second time length, the retention characteristics were different for the two performance modes. Variability across the retention conditions was present

under mental counting while such a tendency was absent under conscious time estimation. The variability of the one second time length was less under mental counting cognitive strategy for all retention conditions.

Similarities between the results of the present study and those obtained for motor short-term memory were the following: (a) the reproduction of a one or four seconds time length under an unfilled retention interval was quite similar to the reproduction of movement information when distance was the only reliable cue; information of this type seems to spontaneously decay (Laabs, 1973); and (b) the reproduction of a one or four seconds time length under a filled retention interval (verbal interpolated task) was quite similar to the results of Laabs (1973) who found that no difference existed between an unfilled and a filled retention interval for movement information (distance).

Summary of Section 2

The results of Section 2 clearly indicate separate memory functions for very short and short time lengths when used in temporal reproduction under conscious time estimation cognitive strategy. Short (greater than 4 seconds) as opposed to very short time lengths under such strategy appear to spontaneously decay, while very short time lengths seem to be rehearsable in some manner even when processing capacity is not available. Furthermore, the results also distinctly reveal a unique memory function for time lengths under mental counting cognitive strategy when used in temporal recall. Time lengths under such strategy appear to spontaneously decay even when processing capacity is available. Finally, the retention characteristics demonstrated under mental counting cognitive strategy were better than under conscious time estimation cognitive strategy.

The constraints leading to the presence of decay for both modes of performance will be investigated in Section 3. Could the rehearsal process or proactive interference be the major cause of forgetting temporal information? This problem will be investigated in the following section.

Section 3

General Purpose of Section 3

Section 3 (Experiments 5, 6 and 7) was performed in order to determine why temporal information was not retained under conscious time estimation and mental counting cognitive strategies in the previous experiments. Rehearsal (Experiment 5) and proactive interference (Experiments 6 and 7) were the two processes investigated in that section under conscious time estimation and mental counting cognitive strategies.

The results of Experiments 2 and 3 were that, for time lengths of four and eight seconds under a conscious time estimation cognitive strategy, subjects became more variable after an unfilled retention interval of 15 seconds or more than if they recalled the item: (a) immediately, or (b) if the item to be remembered was only one or two seconds long. Further, the results of Experiment 4 were that, for time lengths of one and four seconds under a mental counting cognitive strategy, subjects became more variable after an unfilled retention interval of 15 seconds or more. In these studies, a subject-defined rehearsal was used. Subject-defined rehearsal was present when the subjects received no specific instruction as to what to do during the rest retention interval, except to wait quietly.

One might question what the results of the above three studies would be if the subjects were instructed to use an experimenter-defined rehearsal instead of a subject-defined rehearsal during the rest interval. Would this former kind of rehearsal improve, maintain or interfere with the to-be-remembered item after a certain period of time? The purpose of Experiment 5 was to answer this question.

Experiment 5
Types of Rehearsal
and
Retention of Time

Psychologists in the verbal domain have proposed two main functions of the rehearsal process: (a) to renew information in short-term memory so that it is not forgotten, and (b) to transfer information about the rehearsed items to long-term memory, thus building up the strength of the information long-term memory preserves (Atkinson and Shiffrin, 1968; Norman and Rumelhart, 1970, Waugh and Norman, 1965). Furthermore, a number of investigations have led to the need to postulate more than one rehearsal process (for a review see Glenberg, Smith and Green, 1977). Moreover, Tulving (1972) stated that encoding refers to the possibility that the internal representation of a given perceptual input may assume different forms, depending upon certain operations performed upon the input or on its representation in the memory store. Then it is logical to assume that the kind of rehearsal process is closely related to the nature of the representation of the to-be-remembered item (tbri) in memory. The effectiveness of a rehearsal process may depend on the nature of the information that the subjects are processing.

In order to examine the effect of rehearsing temporal information, the following study investigated the retention of temporal information under two forms of

rehearsal: (a) subject-defined rehearsal, and (b) experimenter-defined rehearsal; and two forms of cognitive strategy: (a) conscious time estimation, and (b) mental counting, where the to-be-remembered item consisted of short time lengths, namely one and four seconds reproduced after a retention interval of 15 seconds.

Type I rehearsal or a maintenance (revivification) process as proposed by Craik and Watkins (1973) was used in the present study as opposed to Craik and Lockhart's (1972) Type II rehearsal. It is assumed that a Type I rehearsal process maintains information by rote repetition at a given level of analysis for the duration of the processing activity. The rote repetition may take two forms: (a) overt, and (b) covert. Overt rehearsal is analogous to repeating things out loud or by internal speech (Norman, 1969), while covert rehearsal (something like concentration) is subconscious in that the rehearsal process cannot be readily identified. In the present study it was assumed that the former type of rehearsal could be utilized when subjects were using mental counting as their cognitive strategy, while the latter was probably used when subjects were under a conscious time estimation cognitive strategy.

Method

Subjects

Eight volunteer graduate students in physical education at the University of Alberta were used in this experiment.

Apparatus and Task

The apparatus and the task were the same as those described in Experiment 2 for an unfilled retention interval of 15 seconds.

Design

A factorial design (2 X 2 X 2) in which 4 subjects were assigned to one of two levels of rehearsal condition and then tested under all levels of the other two factors, namely cognitive strategy and time length, were used in the present study. The two levels of rehearsal used were: (a) subject-defined rehearsal (SDR), and (b) experimenter-defined rehearsal (EDR). The two levels of cognitive strategy were: (a) conscious time estimation (CTE), and (b) mental counting (MC); and the two levels of criterion time length were: (a) 1 second, and (b) 4 seconds. Thirty trials were given for each of the 4 treatment conditions.

Procedure

The subjects were given a number of trials to familiarize themselves with the equipment and the retention interval. They attended one session of approximately 60 minutes. The 4 treatment conditions under each level of rehearsal condition were assigned to the subjects, with the order of occurrence determined by rotation in a Latin Square. The rotation in the Latin Square was similar for both levels of rehearsal condition. The task instructions to the subjects concerned five points: (a) the subjects were asked to be as accurate as possible, (b) the subjects were asked to express and demonstrate their understanding of the task, (c) the subjects under the conscious time estimation cognitive strategy were asked not to use any time-aiding technique. The experimenter explained thoroughly what was meant by a time-aiding technique, giving examples of the various kinds, (d) the subjects were asked to use mental counting when asked to do so. The experimenter explained thoroughly what was meant by mental counting (counting to himself), and (e) the subjects under the experimenter-defined rehearsal condition were asked to rehearse (rote repetition) the criterion time length during the retention interval, e.g. they were asked to rehearse the visual time length (covert rehearsal or concentration) or the mental counting (overt rehearsal or internal speech). The subjects under the

subject-defined rehearsal condition were not given this instruction.

Data Analysis

The dependent variables were the same as those described in previous experiments.

Results

Raw Data

The raw time estimation data for all treatment conditions and for each subject were visually inspected. In only a few cases did the data show a lengthening or shortening effect. Consequently, the thirty trials for each subject were reduced to a simple mean.

Time Length

Average performance analysis revealed that the subjects were able to maintain their estimates of one and four seconds as distinct events over experimental conditions, $\underline{F}$ (1,6) = 1001.57, $\underline{p} < .01$. This suggests that when errors arose they were not due to the subjects confusing the two time lengths in memory.

A significant effect of time length was found for absolute error, $\underline{F}$ (1,6) = 16.92, $\underline{p} < .01$, and for variable error, $\underline{F}$ (1,6) = 43.66, $\underline{p} < .01$. The subjects produced

larger errors and were more variable in their estimates of four seconds as compared to one second. However, interactions between time length and cognitive strategy were significant for absolute error, $\underline{F}$ (1,6) = 8.09, $\underline{p} < .05$, and variable error, $\underline{F}$ (1,6) = 9.01, $\underline{p} < .05$. These interaction effects were almost totally due to the four seconds time length when held in memory under the mental counting cognitive strategy (see Figures 14 and 15).

With respect to constant error scores, the time length main effect was not significant ($\underline{p} > .05$). The subjects did not show any directional bias in their estimates of either one or four seconds. This suggests that there was not a development of a central tendency or range effect in the present study.

Cognitive Strategy

There were no significant differences for all dependent measures between conscious time estimation and mental counting ($\underline{p} > .05$). However, because of the significant time length by cognitive strategy interactions noted earlier on the absolute error (AE) and variable error (VE) scores, a Scheffé's test ($\underline{p} < .05$) was run on the simple main effect for AE and VE scores. A significant increase in accuracy and reduction in variability for the 4 seconds time length was revealed when subjects were asked to use mental counting as their cognitive strategy.

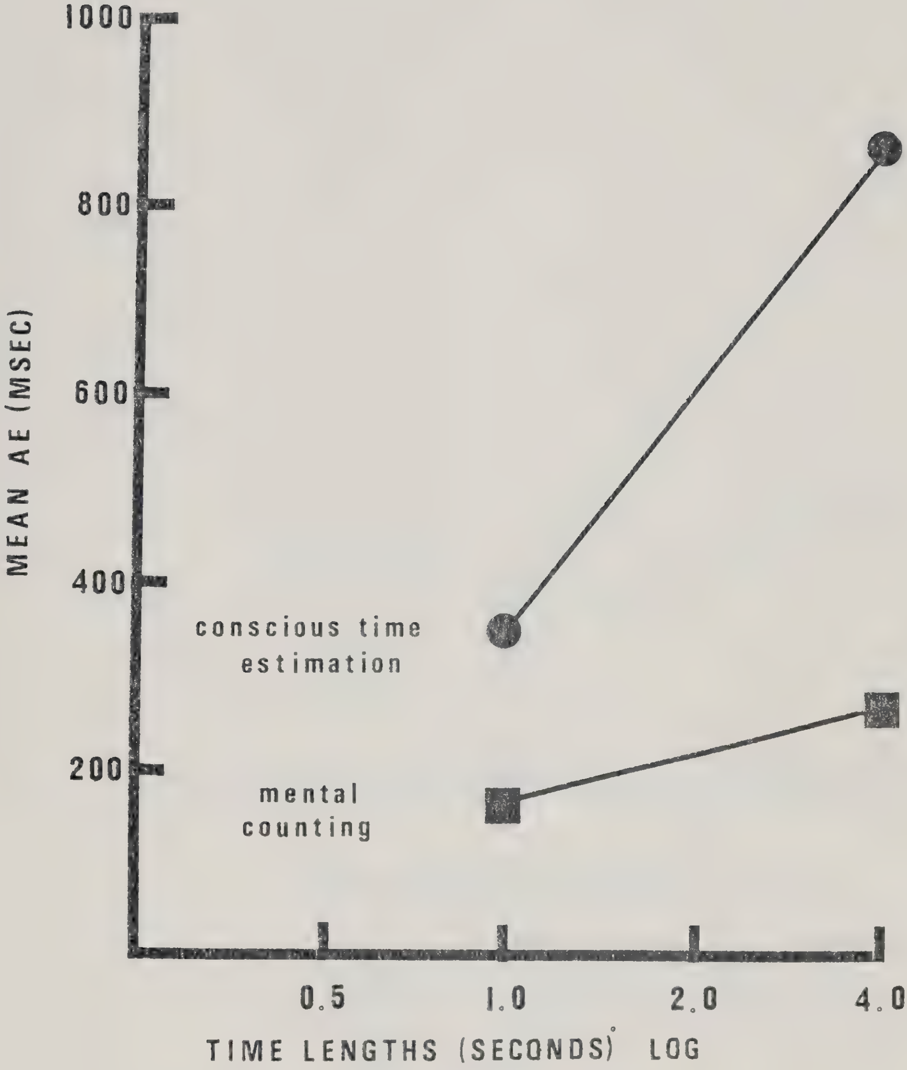


Figure 14 Mean absolute error (AE) for conscious time estimation and mental counting cognitive strategies as a function of the time lengths

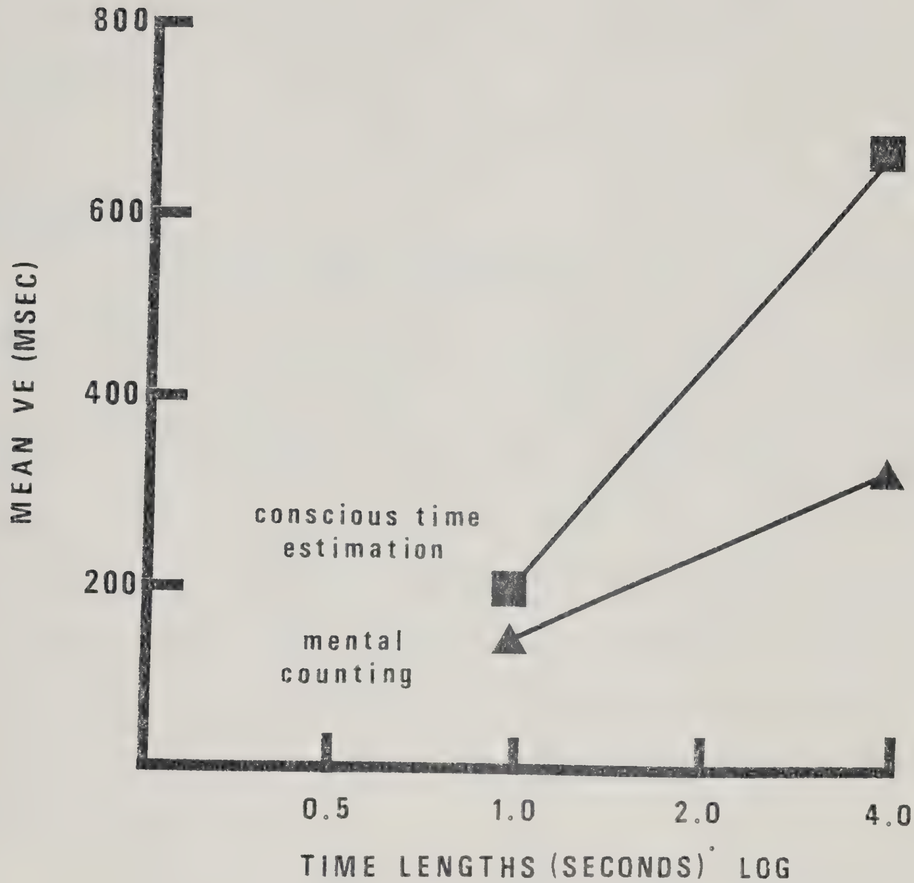


Figure 15 Mean variable error (VE) for conscious time estimation and mental counting cognitive strategies as a function of the time lengths

Subjects reproducing the one second time length either under conscious time estimation or mental counting provided similar results in terms of accuracy and variability.

Rehearsal

For all performance measures, there was no significant difference between the two rehearsal conditions ($p > .05$). Furthermore, no significant interactions involving this factor were noted in the present investigation ($p > .05$). Subjects rehearsing under an experimeter-defined condition with time lengths of one or four seconds either under conscious time estimation or mental counting during a retention interval of 15 seconds did not produce different results from subjects under a subject-defined rehearsal.

The various error scores for each level of time length, cognitive strategy, and rehearsal condition are summarized in Table 7.

Discussion

Time Length and Cognitive Strategy

The present results under an unfilled retention interval of 15 seconds revealed that mental counting did little to improve time estimation accuracy (absolute) or variability relative to conscious time estimation for the

Table 7

Mean VE, AE, AP and CE in Milliseconds
for Time Length, Rehearsal and Cognitive Strategy

Rehearsal[a]	Cognitive Strategy[b]			
	MC		CTE	
	1 second	4 seconds	1 second	4 seconds
		Variable Error (VE)		
EDR	121	203	151	692
SDR	165	432	231	627
		Absolute Error (AE)		
EDR	127	173	158	782
SDR	195	343	528	946
		Average Performance (AP)		
EDR	1060	3962	1123	4533
SDR	1109	4117	1457	4815
		Constant Error (CE)		
EDR	60	- 39	123	533
SDR	109	117	457	815

[a]EDR = experimenter-defined rehearsal
SDR = subject-defined rehearsal

[b]MC = mental counting
CTE = conscious time estimation

one second time length. However, significant reductions in variability and larger improvements in accuracy were found for the four seconds time length.

Rehearsal

Subjects produced similar results under an experimenter-defined rehearsal process and a subject-defined rehearsal process. The experimenter-defined rehearsal process did not enhance or interfere with the recall of the to-be-remembered item (tbri).

A difference between an immediate and a 15 seconds retention interval in terms of accuracy (AE) and variability (VE) for recall of a to-be-remembered item of four seconds under conscious time estimation and a subject-defined rehearsal condition was obtained in Experiment 2. Such a difference was not found for the one second time length. It was expected in the present study that the experimenter-defined rehearsal process for a time length of four seconds under conscious time estimation would improve the results in the direction of an immediate recall and that a difference between the two levels of rehearsal would be present. Such a difference was not obtained in this investigation. Perhaps the subjects under the subject-defined rehearsal might have subconsciously (concentration) rehearsed the to-be-remembered item and consequently equalized the performance of the experimenter-

defined rehearsal group, i.e. subjects do not need to be instructed (experimenter-defined rehearsal) because they are using such rehearsal under subject-defined rehearsal. As for the one second time length, the experimenter-defined rehearsal did not interfere with the to-be-remembered item.

When subjects were under a subject-defined rehearsal condition and a mental counting cognitive strategy for time lengths of one and four seconds, differences between an immediate and a retention interval of 15 seconds, in terms of variability, were found for both durations in Experiment 4. In the present study, mental counting either under experimenter-defined or subject-defined rehearsal maintained the tbri at a similar level of performance after a period of 15 seconds. The experimenter-defined rehearsal condition did not improve the recall of the tbri.

In summary, we might conclude that the utilization of an experimenter-defined rehearsal has no greater advantage than a subject-defined rehearsal technique, and that such instruction has no particular implication in the studies on the memory of time. However, the utilization of an immediate retention interval in the present study might have modified these findings.

The factor under investigation in Experiment 6 was the 'total time' or 'inter-stimulus interval (ISI)'.

An inter-stimulus interval was defined as the sum of four time periods: (a) criterion time length, (b) retention interval, (c) recall period, and (d) intertrial interval. The general purpose of that experiment was to examine proactive interference under various inter-stimulus intervals. To achieve that purpose, three small experiments were done with each, including a particular criterion time length and a particular recall period. Subjects in Experiment 6 were asked to consciously estimate time.

Experiment 6

Proactive Interference and Intertrial Interval in Temporal Short-Term Memory under Conscious Time Estimation

One explanation for forgetting what we once learned is based on the phenomenon of interference. The study of proactive inhibition (PI) provides a better opportunity to observe specific interference due to similarity, since proactive materials do not act to prevent rehearsal (Posner, 1967).

There has been considerable research effort in verbal, motor and nonverbal short-term memory devoted to examine the interfering effects of preceding materials on retention of a criterion item (Ascoli and Schmidt, 1969; Keppel and Underwood, 1962; Meudell, 1977). The evidence in verbal short-term memory (Keppel and Underwood, 1962; Loess, 1964; Peterson and Gentile, 1965) provides strong support for PI as a major cause of forgetting. Proactive interference effect was demonstrated with only one prior item and the effect increased with each successive item entering memory. Several studies in motor short-term memory have reported an interfering effect of prior movement experience (Ascoli and Schmidt, 1969; Burwitz, 1974; Dickinson and Higgins, 1977). Herman and Bailey (1970), Montague and Hillix (1968), and Schmidt and Ascoli (1970), however, found no evidence of PI for motor short-term memory. While in nonverbal short-term memory, a build up of PI was found by Meudell (1977), Wells (1973),

Yarmey (1974), and Yuille and Fox (1973). Proactive interference was found for a long retention interval and PI reaches a maximum after one trial in Meudell's (1977) study. That is, one prior item stored in memory causes as much PI as two prior-stored items.

Similarities in the three storage systems with respect to PI are not limited to the number of prior items and retention intervals for similarities also exist with respect to the effects of the length of the intertrial interval. Proactive interference is inversely related to the length of the intertrial interval in verbal memory (Cermak, 1969; Ellis and Anders, 1967; Loess and Waugh, 1967) whereas it was found to have no effect in producing interference in motor memory (Adams and Dykstra, 1966; Montague and Hillix, 1968; Schmidt and Ascoli, 1970). The role of the intertrial interval variable was considered by Meudell (1977) to be very important in nonverbal memory.

Results on the retention of time under a conscious time estimation cognitive strategy and with unfilled retention intervals were obtained in Experiments 2 and 3. Thirty trials were given for each of the 12 treatments (time lengths - 2 by retention intervals - 6) in Experiment 2. When the 30 trials were divided into 6 blocks of 5 trials each and a one-way analysis of variance was calculated for each treatment, no differences between the blocks were obtained for all analyses of variance on

average performance dependent measure. Similar results, with the same dependent measure, were found when the 20 trials for each of the 20 treatments (time lengths - 4 by retention intervals - 5) in Experiment 3 were divided into 2 blocks of 10 trials each. The results relative to the unfilled retention intervals in Experiment 2 were that subjects were more variable and less accurate (absolute error) when they reproduced a four seconds time length after 15 and 30 seconds than immediately. The findings in Experiment 3 were that subjects were more variable when they reproduced a four or eight seconds time length after 16 seconds than immediately and less accurate (absolute error) when they reproduced a one, two, four or eight seconds time length after 16 seconds than immediately. The intertrial interval was approximately one second long in both experiments.

Inter-stimulus interval (ISI) was variable within each individual time length in Experiments 2 and 3. The variability of ISI was created by the varying length of the retention intervals. Criterion time length, recall period and intertrial interval were always constant in those experiments. To obtain a constant ISI, in the present study for a number of experimental treatments within each individual criterion time length, variable intertrial intervals were introduced in the procedure. One might question what the effects would be of retention

intervals and intertrial intervals on the retention of time with such a procedure.

The role of PI effect in temporal short-term memory was to be examined in the present study. Pooling data across successive blocks of trials in Experiments 2 and 3 provided no evidence or probably masked PI effects. If a trial-by-trial analysis of the data had been made in those studies, perhaps PI effects would have been found. Such effects were demonstrated in the verbal and nonverbal short-term memory after only one prior item (Keppel and Underwood, 1962; Meudell, 1977). More precisely, three questions were to be answered in the present investigation. Firstly, could PI be the major cause of forgetting in Experiments 2 and 3? Secondly, if PI is operating in temporal short-term memory as the number of trials increased, then there should be increasing error over trials for subjects with a short intertrial interval and no trial effects or a decay of interference for subjects with longer intertrial intervals. Finally, the critical issue is whether or not verbal short-term memory, motor short-term memory, nonverbal short-term memory and temporal short-term memory will require fundamentally different interpretative principles.

The purpose of this investigation was to answer these questions. To achieve that purpose, three criterion time lengths, three retention intervals and three

intertrial intervals were utilized under a conscious time estimation cognitive strategy. Three separate experiments (one for each criterion time length) were run using the same subjects.

Method

Subjects

Eighteen volunteer students in physical education at the University of Alberta were used in this experiment.

Apparatus and Task

The apparatus and the task were the same as those described in Experiment 2 with the following additions.

Two additional decade interval timers (Hunter 111-C and 100-C) were used. These timers were connected to a tone generator (Eico 377),amplifier and speaker. When the circuit controlling the criterion time length had cycled through its pre-set time length, an audible tone was provided to the subjects after a period of time. Following the tone, which signified the end of the retention interval, the subjects were asked to reproduce the criterion time length. Then the subjects were asked by the experimenter to wait for a second tone to be provided before they operated the left trigger in order to receive another criterion time length. The second tone marked the end of the intertrial interval, which refers to the

period of time between the end of the recall period and the ready signal preceding the next trial.

Design

For each time length: (a) one second, (b) four seconds, and (c) eight seconds, three retention intervals were used: (a) immediate or one second (R.1), (b) 15 seconds (R.15) and (c) 30 seconds (R.30). These three levels of retention interval were combined factorially in a treatment by subjects' design with three levels of intertrial interval: (a) immediate or one second (ITI.1), (b) 15 seconds (ITI.15), and (c) 30 seconds (ITI.30). Six trials were given for each of the nine treatments (see Table 8).

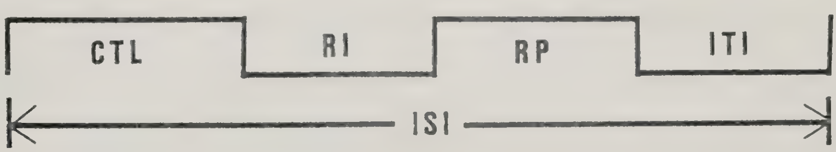
Recall Period

The recall periods for each criterion time length were determined by using the results of Experiment 3 on average performance and variable error scores. It was decided that the recall periods for the one, four and eight seconds time lengths of the present study would be two, six and ten seconds, respectively. When the subjects' reproductions exceeded that period of recall, another trial was given.

Table 8

Treatment Conditions (9) for the
One, Four and Eight seconds Time Lengths

	Treatment conditions								
	1	2	3	4	5	6	7	8	9
CTL[a]	1	1	1	1	1	1	1	1	1
RI[b]	1	1	1	15	15	15	30	30	30
RP[c]	2	2	2	2	2	2	2	2	2
ITI[d]	1	15	30	1	15	30	1	15	30
ISI[e]	5	19	34	19	33	48	34	48	63
CTL	4	4	4	4	4	4	4	4	4
RI	1	1	1	15	15	15	30	30	30
RP	6	6	6	6	6	6	6	6	6
ITI	1	15	30	1	15	30	1	15	30
ISI	12	26	41	26	40	55	41	55	70
CTL	8	8	8	8	8	8	8	8	8
RI	1	1	1	15	15	15	30	30	30
RP	10	10	10	10	10	10	10	10	10
ITI	1	15	30	1	15	30	1	15	30
ISI	20	34	49	34	48	63	49	63	78



[a] Criterion time length in seconds.
[b] Retention interval in seconds.
[c] Recall period in seconds.
[d] Intertrial interval in seconds.
[e] Inter-stimulus interval in seconds.

Procedure

The subjects were given a number of trials to familiarize themselves with the equipment and the demands of the task. They attended three sessions of approximately 70 minutes each in length. One time length was used within each session. Six orders of criterion time length were used: (a) one, four and eight seconds, (b) four, eight and one second, (c) eight, one and four seconds, (d) one, eight and four seconds, (e) four, one and eight seconds, and (f) eight, four and one second. Three subjects were assigned at random for each order. Each subject was given nine treatment conditions (retention intervals by intertrial intervals) or 54 trials (6 trials per treatment condition) per session. In order to have each treatment follow immediately after every other treatment an equal number of times, the order of occurrence of the 9 treatment conditions was determined by two 9 X 9 Latin Squares, each row of each square corresponding to one subject. A rest of two minutes was given between each treatment condition.

The following instructions were read to each subject: (a) the subject was asked to be as accurate as possible, (b) the subject was asked to express and demonstrate his understanding of the task, (c) the subject was asked to concentrate on the input (criterion time length) during the retention interval (unfilled interval), (d) the subject was asked not to use any

time-aiding technique at any time. The experimenter explained thoroughly what was meant by a time-aiding technique, giving examples of the various kinds, and (e) the subject was asked to wait until he heard a first tone in order to receive the criterion time length and another tone before reproducing the to-be-remembered item.

Data Analysis

The dependent variables used were: (a) signed constant error (CE), (b) absolute error (AE), and (c) variable error (VE). For CE and AE dependent measures, three factors were considered: (a) retention intervals, (b) intertrial intervals, and (c) trials. If a build-up of PI is to be obtained, increasing error with trials, increasing error for longer retention intervals, and an interaction between retention intervals and trials should be found in the present study. Whereas, if a decay of interference is to occur, increasing error with trials, increasing error for shorter intertrial intervals, and an interaction between intertrial intervals and trials should appear in the present investigation. When VE dependent measure was considered, only two factors were used: (a) retention intervals, and (b) intertrial intervals. The latter measurement was used in order to compare the present results with those of Experiments 2 and 3.

Results

One Second Time Length

Recall Period

All subjects' reproductions of the one second time length did not exceed the two seconds period of recall. Only one trial was repeated.

Constant Error (CE)

A significant effect for CE, F (2,34) = 5.86, $p < .01$, was found for retention intervals. A Scheffé's test ($p < .05$) on the retention intervals' main effect was run. The immediate retention interval was significantly different from the 15 seconds retention interval. All other main effects and interactions did not reach the conventional level of significance ($p < .05$).

Subjects tended to overestimate the one second time length, with an average error of +168 milliseconds. There was a tendency for this degree of overestimation to decrease with an increase in retention intervals. This finding was contrary to the prediction expected if PI were operating. A build-up of PI should have caused increasing error with trials, increasing error for longer retention intervals, and an interaction between retention intervals and trials. The presence of interference was not supported for CE and the one second time length. The tendency found

above for retention intervals was also present for each individual intertrial interval. There was also a tendency for this degree of overestimation to increase slightly with an increase in intertrial interval. An opposite result should have occurred if decay of interference were present. Decay of interference should cause increasing error with trials, increasing error for shorter intertrial intervals, and an interaction between intertrial intervals and trials. Decay of interference was not supported for the the present results. The CE scores for the one second time length as a function of retention intervals and intertrial intervals are summarized in Table 9.

Absolute Error (AE)

All main effects and interactions for AE scores were not found to be significant ($p > .05$).

Subjects estimated the one second time length with an average error of 269 milliseconds. As with CE, the lack of an increasing AE with trials and retention intervals, and the lack of an interaction between trials and retention intervals failed to provide support for the presence of interference. The lack of an increasing AE with trials and intertrial intervals, and the lack of an interaction between trials and intertrial intervals failed also to support decay of interference. The AE scores for the one second time length as a function of retention

Table 9

The various Error Scores in Milliseconds for the One second Time Length as a function of Retention Intervals and Intertrial Intervals

		Intertrial Intervals[a]			
CONSTANT ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals[b]	R.1	+ 216	+ 222	+ 227	+ 222
	R.15	+ 110	+ 111	+ 141	+ 121
	R.30	+ 181	+ 146	+ 157	+ 161
	MEAN	+ 169	+ 160	+ 175	+ 168
ABSOLUTE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	279	260	308	282
	R.15	234	240	258	244
	R.30	279	277	289	282
	MEAN	264	259	285	269
VARIABLE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	128	131	172	144
	R.15	158	168	161	162
	R.30	157	154	179	163
	MEAN	148	151	171	156

[a] ITI.1 = 1 second
ITI.15 = 15 seconds
ITI.30 = 30 seconds

[b] R.1 = 1 second
R.15 = 15 seconds
R.30 = 30 seconds

intervals and intertrial intervals are summarized in Table 9.

Variable Error (VE)

Retention intervals and intertrial intervals main effects, and the interaction between retention intervals and intertrial intervals were not found to be significant ($p > .05$).

Subjects estimated the one second time length with an average error of 156 milliseconds. The VE scores for the one second time length as a function of retention intervals and intertrial intervals are summarized in Table 9.

Inter-Stimulus Interval (ISI)

An increase of ISI produced a slight decrease in the degree of overestimation for the 15 seconds retention interval. The decrease was not demonstrated for the 30 seconds retention interval. The tendency could not be considered as a general phenomenon. An increase of ISI produced no particular trend for AE and VE dependent measures.

Discussion

The present results provided no support that PI effects were operating in temporal STM for the one second

time length. It seems clear from the present findings that the reason for the lack of PI over trials and retention intervals was not related to the intertrial intervals for even when the intertrial intervals in the present investigation were shortened to 1 second, no PI could be demonstrated. Increasing ISI revealed no particular trend for the one second duration.

Similarities between the results of the present study and those obtained for Experiments 2 and 3 were the following. Relative to CE scores, there was a slight tendency for the degree of overestimation to decrease with an increase in retention intervals (Experiments 2 and 3). No differences were found between the various retention intervals in terms of AE scores (Experiment 2), a finding contrary to Experiment 3 where a decrease of accuracy was found after a retention interval of 16 seconds. In terms of VE, there were no differences between the various retention intervals (Experiments 2 and 3). The present results, for all dependent measures were quite similar to the results obtained in Experiment 5 under a similar rehearsal condition.

Four Seconds Time Length

Recall Period

All subjects' reproductions of the four seconds time length did not exceed the six seconds period of recall. Only one trial was repeated.

<u>Constant Error (CE)</u>

All main effects and interactions for CE scores were not found to be significant ($p > .05$).

Subjects tended to underestimate the four seconds time length with an average error of -338 milliseconds. There was a tendency (not significant) for this degree of underestimation to decrease with an increase in retention intervals. This finding was contrary to the predictions expected if PI were operating. The lack of an increasing CE with trials and retention intervals, and the lack of an interaction between trials and retention intervals failed to provide support for the presence of interference. The lack of an increasing CE with trials and intertrial intervals, and the lack of an interaction between trials and intertrial intervals failed also to support decay of interference. The CE scores for the four seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 10.

<u>Absolute Error (AE)</u>

All main effects and interactions for AE scores were not found to be significant ($p > .05$).

Subjects estimated the four seconds time length with an average error of 844 milliseconds. The results provided no support for the presence of interference and/or decay of interference. The AE scores for the four seconds

Table 10

The various Error Scores in Milliseconds for the Four seconds Time Length as a function of Retention Intervals and Intertrial Intervals

		Intertrial Intervals[a]			
CONSTANT ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals[b]	R.1	- 461	- 406	- 375	- 414
	R.15	- 370	- 316	- 266	- 317
	R.30	- 290	- 348	- 208	- 282
	MEAN	- 374	- 357	- 283	- 338
ABSOLUTE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	862	800	760	807
	R.15	865	887	775	842
	R.30	900	845	898	881
	MEAN	876	844	811	844
VARIABLE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	332	380	399	370
	R.15	506	512	486	501
	R.30	571	457	496	508
	MEAN	470	450	460	460

[a] ITI.1 = 1 second
ITI.15 = 15 seconds
ITI.30 = 30 seconds

[b] R.1 = 1 second
R.15 = 15 seconds
R.30 = 30 seconds

time length as a function of retention intervals and intertrial intervals are summarized in Table 10.

Variable Error (VE)

A significant effect for VE, F (2,34) = 8.56, $p < .01$, was found for retention intervals. A Scheffé's test ($p < .05$) on the retention intervals' main effect was run. The immediate retention interval was significantly different than the 15 and 30 seconds retention intervals (see Figure 16). Subjects were less variable when they reproduced after an immediate retention interval than the other two intervals. The main effect of intertrial intervals and the interaction between retention intervals and intertrial intervals did not reach the accepted level of significance ($p < .05$).

Subjects estimated the four seconds time length with an average error of 460 milliseconds. The VE scores for the four seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 10.

Inter-Stimulus Interval (ISI)

An increase of ISI produced an increase in VE scores. The increase was totally due to the retention intervals found previously significant (see Figure 17). Increasing ISI was found to produce no particular trend

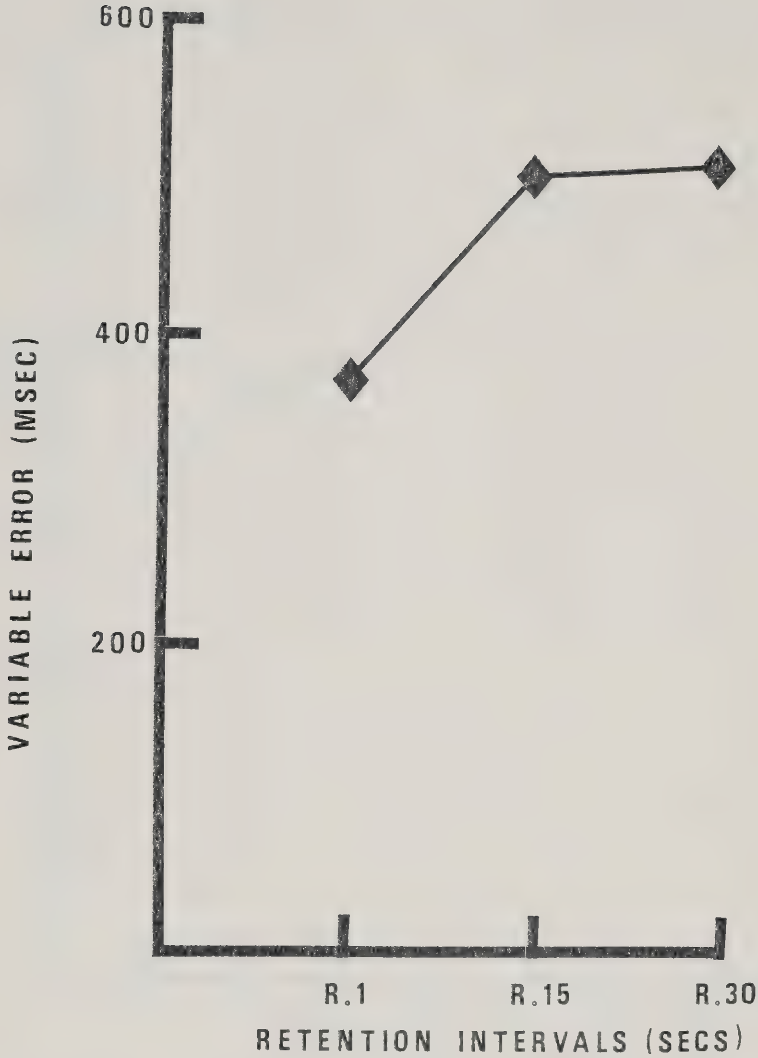


Figure 16 Mean variable error (VE) for the 4 seconds time length as a function of the retention intervals (R.1 = 1 second; R.15 = 15 seconds; R.30 = 30 seconds)

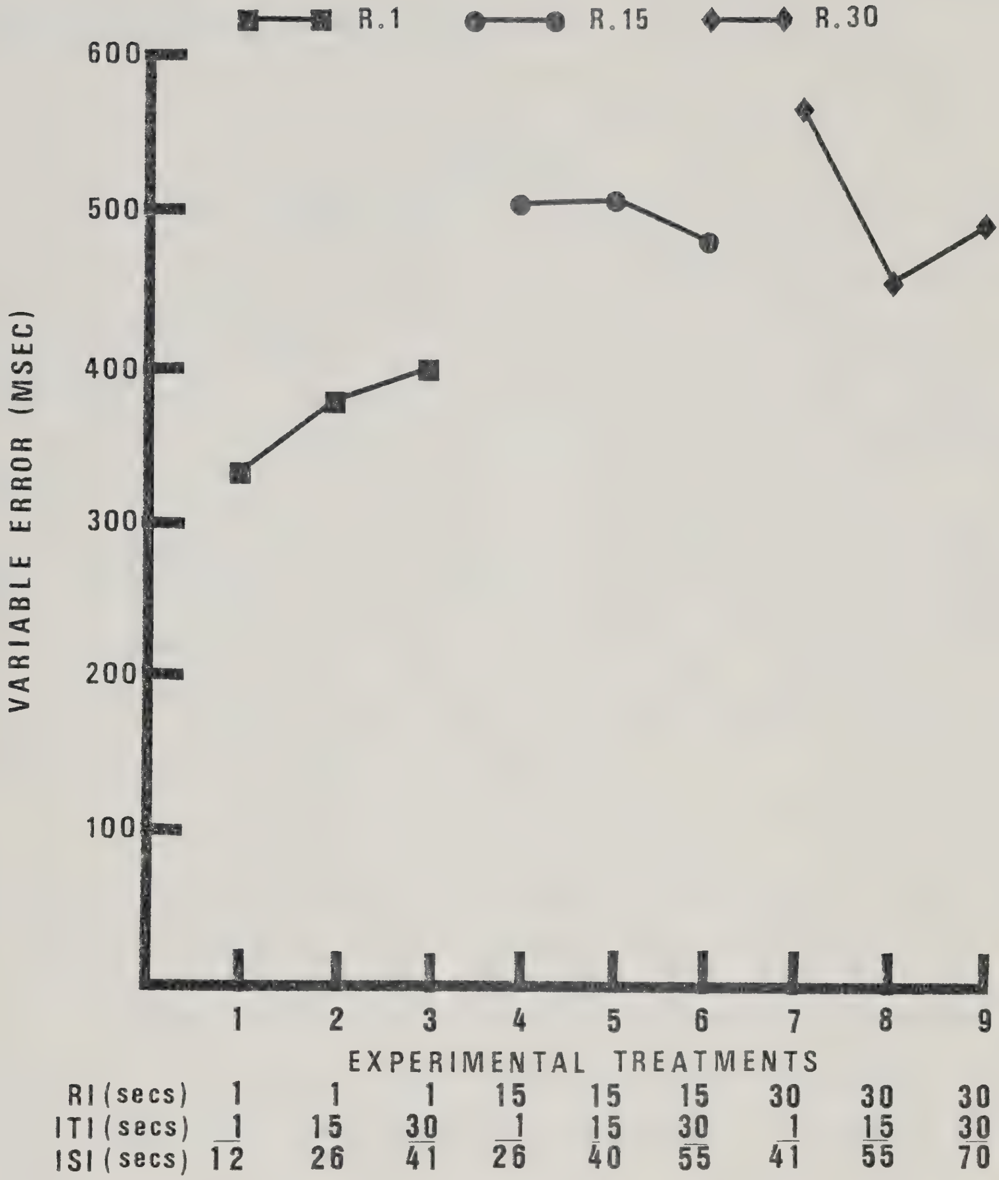


Figure 17 Mean variable error (VE) for the 4 seconds time length as a function of the experimental treatments (RI = retention intervals; ITI = intertrial intervals; ISI = inter-stimulus intervals)

for CE and AE dependent measures.

Discussion

The present results provided no support to state that PI effects were operating in temporal STM for the four seconds time length. It seems clear from the present findings that the reason for the lack of PI over trials and retention intervals was not related to the intertrial intervals; even when the intertrial intervals in the present investigation were shortened to one second, PI could not be demonstrated. Subjects' estimates were more variable as ISI increased and such tendency was the result of an increase of the retention intervals.

Similarities between the results of the present study and those obtained for Experiments 2 and 3 were the following. Relative to CE scores, there were no differences between the various retention intervals (Experiments 2 and 3). In terms of AE, there were no differences between the various retention intervals. A finding contrary to Experiments 2 and 3 where a decrease of accuracy was found after a retention interval of 15 seconds. The present investigation supported the increase in variability found between the various retention intervals in Experiments 2 and 3. The present results were quite similar to the results obtained in Experiment 5 under a similar rehearsal condition with the exception of the CE

dependent measure. Subjects underestimated with an average error of -370 milliseconds in the present study while they overestimated with an average error of +533 milliseconds in Experiment 5.

Eight Seconds Time Length

Recall Period

In the present investigation, 42 trials exceeded the ten seconds period of recall and were repeated. Thirty of those trials were the results of one particular subject. The distribution of the repeated trials were as follows: (a) eight trials for R.1, (b) twenty-six trials for R.15, and (c) eight trials for R.30.

Constant Error (CE)

A significant effect for CE, F (2,34) = 7.58, $p < .01$, was found for retention intervals. A Scheffé's test ($p < .05$) on the retention intervals' main effect was run. The immediate retention interval was significantly different from the 15 and 30 seconds retention intervals (see Figure 18). All other main effects and interactions did not reach the conventional level of significance ($p < .05$).

Subjects tended to underestimate the eight seconds time length with an average error of -1319 milli-seconds. There was a tendency for this degree of under-

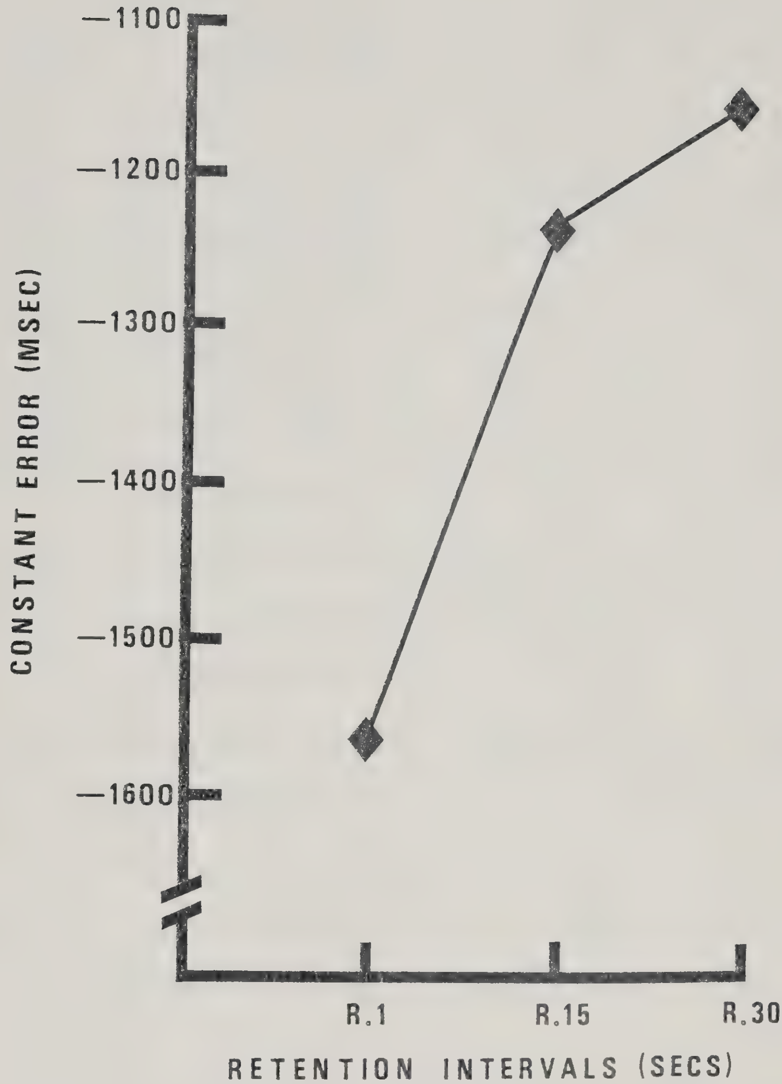


Figure 18 Mean constant error (CE) for the 8 seconds time length as a function of the retention intervals (R.1 = 1 second; R.15 = 15 seconds; R.30 = 30 seconds)

estimation to decrease with an increase in retention intervals, a finding contrary to the prediction expected if PI was operating. A build-up of PI should cause increasing error with trials, increasing error for longer retention intervals, and an interaction between retention intervals and trials. The presence of interference was not supported for CE and the eight seconds time length. The tendency found above for retention intervals was also present for each intertrial interval. There was also a tendency for this degree of underestimation to increase slightly with an increase of intertrial intervals. This is a finding contrary to the prediction expected if decay of interference was present. Decay of interference should cause increasing error with trials, increasing error for shorter intertrial intervals, and an interaction between intertrial intervals and trials. Decay of interference was not supported for the present results. The CE scores for the eight seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 11.

Absolute Error (AE)

All main effects and interactions for AE scores were not found to be significant ($p > .05$).

Subjects estimated the eight seconds time length with an average error of 1700 milliseconds. The lack of an

Table 11

The various Error Scores in Milliseconds for the Eight seconds Time Length as a function of Retention Intervals and Intertrial Intervals

		Intertrial Intervals[a]			
CONSTANT ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals[b]	R.1	-1529	-1524	-1652	-1568
	R.15	-1156	-1340	-1219	-1238
	R.30	-1098	-1173	-1184	-1152
	MEAN	-1261	-1346	-1352	-1319
ABSOLUTE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	1826	1785	1807	1806
	R.15	1514	1791	1699	1668
	R.30	1619	1611	1649	1626
	MEAN	1653	1729	1718	1700
VARIABLE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	710	713	807	743
	R.15	944	872	967	928
	R.30	909	954	890	918
	MEAN	854	846	888	863

[a] ITI.1 = 1 second
ITI.15 = 15 seconds
ITI.30 = 30 seconds

[b] R.1 = 1 second
R.15 = 15 seconds
R.30 = 30 seconds

increasing AE with trials and retention intervals, and the lack of an interaction between trials and retention intervals failed to provide support for the presence of interference. The lack of an increasing AE with trials and intertrial intervals, and the lack of an interaction between trials and intertrial intervals failed to support decay of interference. The AE scores for the eight seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 11.

Variable Error (VE)

A significant effect for VE, F (2,34) = 3.37, $p \leq .05$, was found for retention intervals. A Scheffé's test ($p \leq .10$) on the retention intervals' main effect was run. The immediate retention interval was significantly different from the 15 and 30 seconds retention intervals (see Figure 19). Subjects were less variable when they reproduced after an immediate retention interval than the other two retention intervals. The main effect of intertrial intervals and the interaction between retention intervals and intertrial intervals did not reach the conventional level of significance ($p \leq .05$).

Subjects estimated the eight seconds time length with an average error of 863 milliseconds. The VE scores for the eight seconds time length as a function of retention intervals and intertrial intervals are summarized in

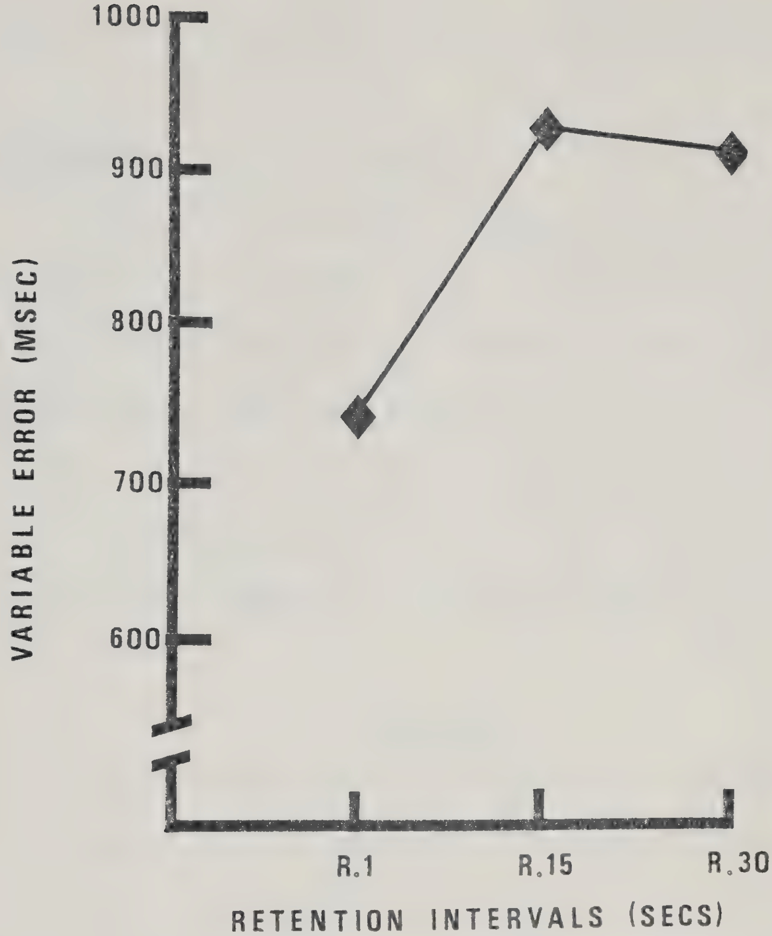


Figure 19 Mean variable error (VE) for the 8 seconds time length as a function of the retention intervals (R.1 = 1 second; R.15 = 15 seconds; R.30 = 30 seconds)

Table 11.

Inter-Stimulus Interval (ISI)

Subjects were more variable in their estimates as ISI increased (see Figure 20). Further, an increase of ISI produced a decrease of constant error scores, i.e. towards the zero point or indifference interval (see Figure 20). Both trends were due to the retention intervals found previously significant. For AE scores, no particular trend appeared with an increase of ISI.

Discussion

The present results provided no support to state that PI effects were operating in temporal STM for the eight seconds time length. It seems clear from the present findings that the reason for the lack of PI over trials and retention intervals was not related to the intertrial intervals; even when the intertrial intervals in the present investigation were shortened to one second, no PI could be demonstrated. Subjects' estimates were more accurate (CE) and more variable (VE) with an increase of ISI.

Similarities between the results of the present study and those obtained for Experiment 3 were the following. Relative to CE scores, there was a tendency for the degree of underestimation to decrease with an increase in

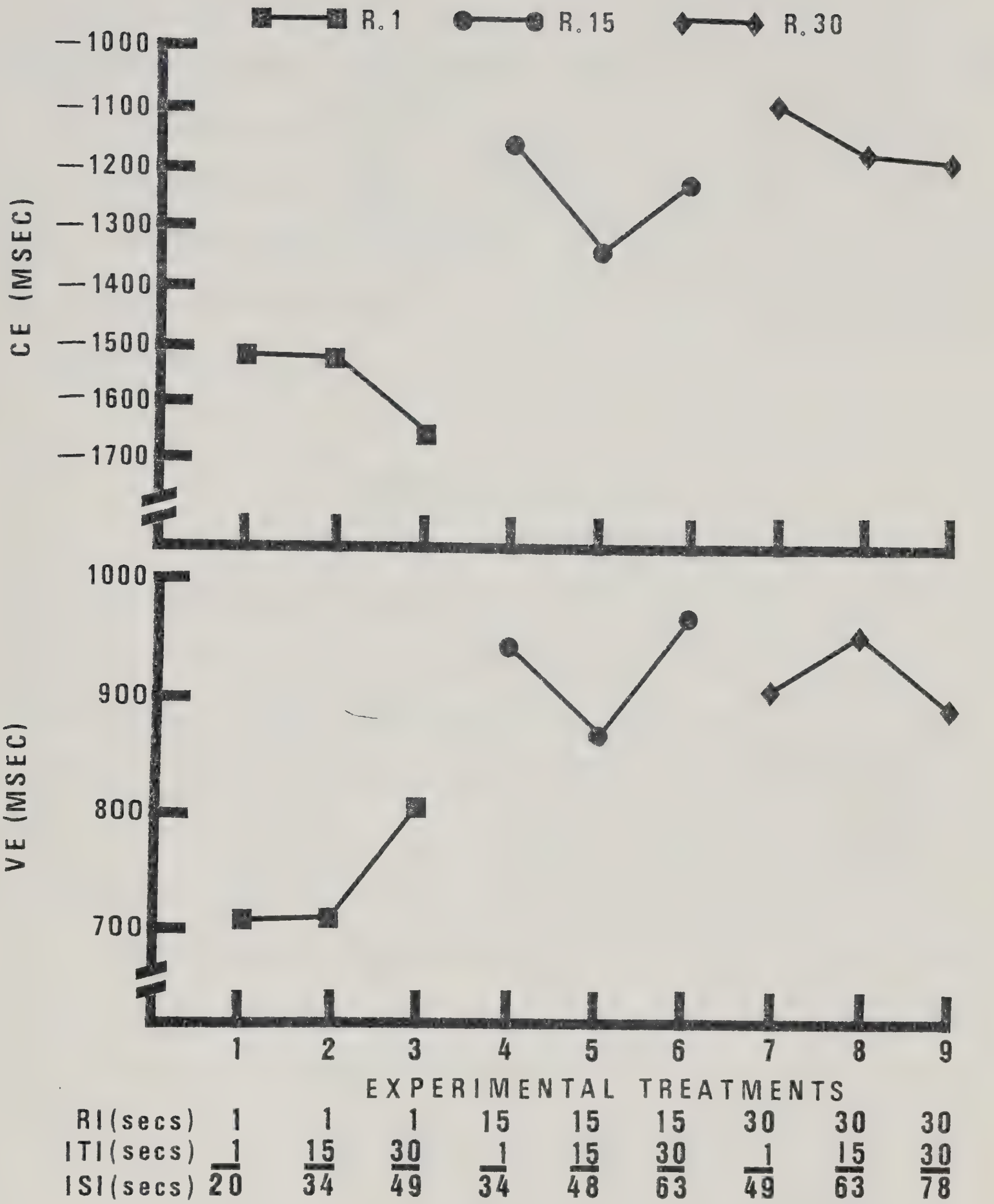


Figure 20 Mean constant error (CE) and variable error (VE) for the 8 seconds time length as a function of the experimental treatments (RI = retention intervals; ITI = intertrial intervals; ISI = inter-stimulus intervals)

retention intervals. In terms of AE, there were no differences between the various retention intervals. This finding is contrary to Experiment 3 where a decrease of accuracy was found after a retention interval of 16 seconds. The present investigation supported the increase in variability found between the various retention intervals in Experiment 3.

General Discussion

The present results, using both CE and AE, dependent measures, under conscious time estimation cognitive strategy for the one, the four and the eight seconds time lengths provided no support to state that PI effects were operating in temporal short-term memory (STM). The lack of PI or a possible decay of interference was not caused by the use of long intertrial intervals; even when the intertrial intervals were shortened to one second, no PI could be demonstrated. The absence of PI could be ascribed to the following reasons: (a) the experimental conditions did not produce any PI effects, (b) PI effects were operating but were not detectable, and (c) PI effects were produced but due to the experimental procedures a release of PI occurred. The first of these three reasons would seem to be more appropriate for the present study.

There appears to be a fundamental difference

in the way verbal, nonverbal, motor and temporal materials are forgotten. Proactive interference effects were demonstrated for verbal, nonverbal and motor materials (Ascoli and Schmidt, 1969; Keppel and Underwood, 1962; Meudell, 1977), and no measurable PI effects for temporal responses. The present experimental conditions were not analogous to those commonly used for verbal, nonverbal and motor materials (i.e. there was an opportunity for rehearsal during the retention interval in the present study). The main reason for the differential conditions was the result of the data obtained in Experiment 2 under unfilled and filled retention intervals. No difference between the results obtained under an opportunity versus no opportunity for rehearsal during the retention interval was observed. Under such a finding, it was concluded that a non-structural interpolated task (backward counting) produced similar results to those obtained under a rest (subject-defined rehearsal) retention interval.

The results obtained under verbal, nonverbal, motor and temporal conditions were quite similar. The temptation is to conclude that the different STM systems do not follow the same laws. The verbal, nonverbal and motor systems, being governed by interference, and the temporal system by some other mechanism, possible trace decay. The present findings in terms of CE and AE scores differed from the results of Experiments 2 and 3 where

differences between the various retention intervals were obtained under both dependent measures. It is possible that one of the instructions given to the subjects was the principal factor in producing such results and that rehearsal is of prime importance. The instruction to concentrate on the input (experimenter-defined rehearsal) during the retention interval would change some conclusions obtained in Experiments 2 and 3. If the experimenter-defined rehearsal (attention demand) is powerful, it should not produce greater variability as retention intervals increase. This was not the case for the four and eight seconds time lengths. Consequently, the present results for the four and eight seconds time lengths under conscious time estimation seem to follow a trace decay explanation.

Inter-stimulus interval produced different results only when there was an increase in retention intervals for the four and eight seconds time lengths. The particular trend observed was that subjects' estimates became more variable as ISI increased. Inter-stimulus interval was not influenced at all by the different intertrial intervals.

A theory of temporal short-term memory was proposed in Experiment 2 which speculated that time lengths of four seconds or more exceed immediate memory span and suffer accordingly. The present results support the notion of a time length constraint on temporal short-term memory.

Again, the results of the analysis of the VE scores are equivocal in their support of the single trace and/or the dual memory trace theories. The retention characteristics for the one second time length are in line with the single trace model, while the increased variability of the four and eight seconds time lengths supports the dual trace notion.

It is now well known in time estimation studies that the number of trials (trial effect) may produce one of three kinds of phenomenon or trend (Buckolz, 1972; Buckolz and Guay, 1975; Treisman, 1963; Warm, Morris and Kew, 1963). A lengthening (increase of judgment from one trial to another), a shortening (decrease) or an asymptotic (no increase and no decrease) effect may be demonstrated. The presence of these trends depends on various factors. Under the method of reproduction and an experimenter-defined pace, the present results demonstrated an asymptotic level. The present trend is similar to the one obtained by Buckolz (1972), Buckolz and Gervais (1976), and Buckolz and Guay (1975). Those studies were done with the method of reproduction, with time lengths within a range of 0.5 to 8.0 seconds, and with a self-paced procedure (i.e. the subject controlled the initiation of the criterion time length to be estimated and the judgment to be reproduced). They concluded that their results may be interpreted as indicative of self-pacing as destroying the lengthening or shortening effects as well as the effect

of boredom. The physical involvement of the subject for the criterion and the judgment in the present study appear sufficient to destroy those effects found in time estimation studies. There is reason to believe that such involvement in a simple task like reproduction is enough to destroy the effect of boredom.

Proactive interference was not found under conscious time estimation cognitive strategy and short time lengths in the present study. Could proactive interference be demonstrated under mental counting cognitive strategy? The following experiment will investigate that question.

Experiment 7

Proactive Interference and Intertrial Interval

in

Temporal Short-Term Memory under Mental Counting

Results on the retention of time under a mental counting cognitive strategy and with unfilled retention intervals were obtained in Experiment 4. It was demonstrated that subjects were more variable when they reproduced the one and four seconds time lengths after 15 and 30 seconds than immediately. The intertrial interval used in that study was approximately of one second's length. Thirty trials, in that experiment, were given for each of the 12 treatments (time lengths - 2 by retention intervals - 6). When the 30 trials were divided into 6 blocks of 5 trials each and a one-way analysis of variance was calculated for each treatment, no differences between the blocks were obtained for all analyses of variance on average performance dependent measure.

The inter-stimulus interval (ISI) was variable within each individual time length in Experiment 4. The variability of the ISI was created by the varying length of the retention intervals. At the same time criterion time length, recall period and intertrial interval were held constant. To obtain a constant ISI for certain conditions within each individual criterion time length, variable intertrial intervals were introduced in the procedure of the present study. One might question what the effects would be of retention intervals and intertrial

intervals on the retention of time if such a procedure was utilized. The procedure used was the same as the one in Experiment 6.

The purpose of this investigation then, was to address that question. A second purpose was to detect the presence of PI effects with a detailed analysis of the trial factor. To achieve these purposes, three criterion time lengths, three retention intervals and three inter-trial intervals were used under a mental counting cognitive strategy. Three separate experiments (one for each criterion time length) were run using the same subjects.

Method

Subjects

Eighteen volunteer students in physical education at the University of Alberta were used in this experiment.

Apparatus, Task, Design, Recall Period, Procedure and Data Analysis

The apparatus, the task, the design, the recall period, the procedure and the data analysis were the same as those described in Experiment 6 with a few modifications in the instructions to the subjects. These changes occurred in instructions (c) and (d) from the procedure section of Experiment 6 and were as follows: (c) the subject was

asked to rehearse (overt rehearsal) the criterion time length during the unfilled retention interval, and (d) the subject was asked to use a mental counting cognitive strategy. The experimenter explained thoroughly what was meant by the latter. Moreover, the subjects were told that the memory of a time length under a mental counting cognitive strategy implies that they retain a 'number' of subjective time units as well as the 'length' of the subjective time unit (counting rate). The subjects were told to pay attention to both variables. The subjects were also asked to give the 'number' of subjective time units used after each recall.

Results

Recall Periods

All subjects' reproductions of the one, four and eight seconds time lengths did no exceed the two, six and ten seconds periods of recall, respectively.

One Second Time Length

Constant Error (CE)

A significant effect for CE, F (2,34) = 3.91, $p < .05$, was found for retention intervals. A Scheffé's test ($p < .05$) on the retention intervals' main effect was run. No meaningful differences were obtained. The

main effect of intertrial intervals was also found significant, F (2,34) = 5.23, $p \leq .05$. Significant differences were found between the one and 15 seconds, and the one and 30 seconds intertrial intervals using the Scheffé's test ($p \leq .05$) (see Figure 21). The trials' main effect and all interactions did not reach the conventional level of significance ($p \leq .05$).

Subjects tended to overestimate the one second time length with an average error of +56 milliseconds. There was a tendency for this degree of overestimation to decrease with an increase in retention intervals. This finding was contrary to the expected PI effect. The presence of interference was not supported for CE and the one second time length. The tendency found above for retention intervals was also present for each individual intertrial interval. There was also a tendency for this degree of overestimation to increase with an increase in intertrial intervals. Once again, the finding was contrary to that expected had the interference decayed. Decay of interference was not supported for the present results. The CE scores for the one second time length as a function of retention intervals and intertrial intervals are summarized in Table 12.

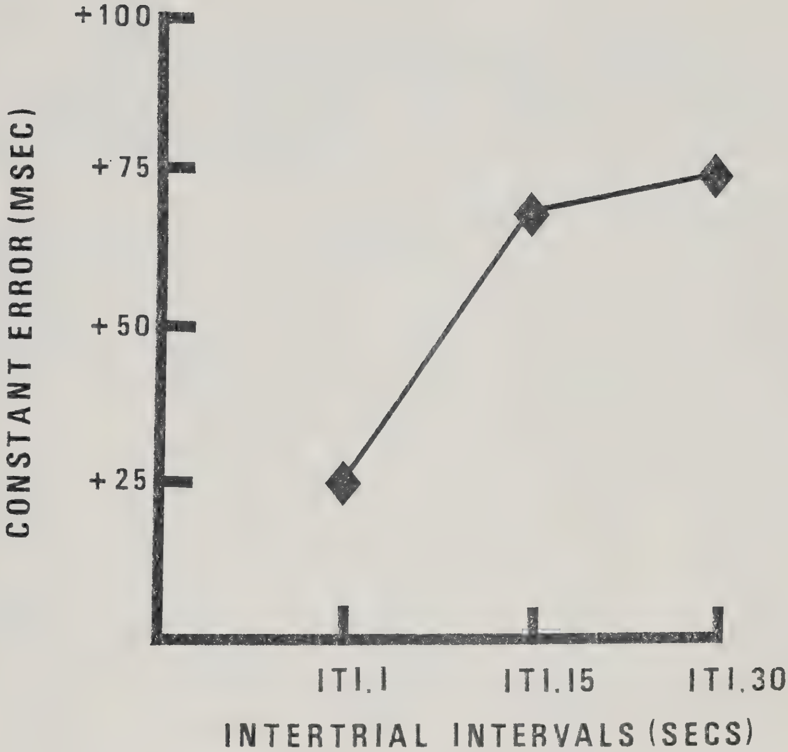


Figure 21 Mean constant error (CE) for the 1 second time length as a function of the intertrial intervals (ITI.1 = 1 second; ITI.15 = 15 seconds; ITI.30 = 30 seconds)

Table 12

The various Error Scores in Milliseconds for the One second Time Length as a function of Retention Intervals and Intertrial Intervals

		Intertrial Intervals[a]			
CONSTANT ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals[b]	R.1	+ 80	+ 81	+ 112	+ 91
	R.15	+ 7	+ 65	+ 46	+ 39
	R.30	− 10	+ 61	+ 67	+ 39
	MEAN	+ 26	+ 69	+ 75	+ 56
ABSOLUTE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	129	151	145	142
	R.15	151	144	140	145
	R.30	152	156	125	144
	MEAN	144	150	137	144
VARIABLE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	109	118	113	113
	R.15	148	103	124	125
	R.30	145	136	114	132
	MEAN	134	119	117	123

[a] ITI.1 = 1 second
ITI.15 = 15 seconds
ITI.30 = 30 seconds

[b] R.1 = 1 second
R.15 = 15 seconds
R.30 = 30 seconds

Absolute Error (AE)

All main effects and interactions for AE scores were not found to be significant ($p > .05$).

Subjects estimated the one second time length with an average error of 144 milliseconds. Absolute error scores failed to provide support for the presence of interference and decay of interference. The AE scores for the one second time length as a function of retention intervals and intertrial intervals are summarized in Table 12.

Variable Error (VE)

Retention intervals' and intertrial intervals' main effects, and the interaction between retention intervals and intertrial intervals were not found to be significant ($p > .05$).

Subjects estimated the one second time length with an average error of 123 milliseconds. The VE scores for the one second time length as a function of retention intervals and intertrial intervals are summarized in Table 12.

Inter-Stimulus Interval (ISI)

Increasing ISI produced an increase in the degree of overestimation due to the intertrial intervals found previously significant (see Figure 22). Subjects' estimates were more accurate (CE) with an ISI composed of

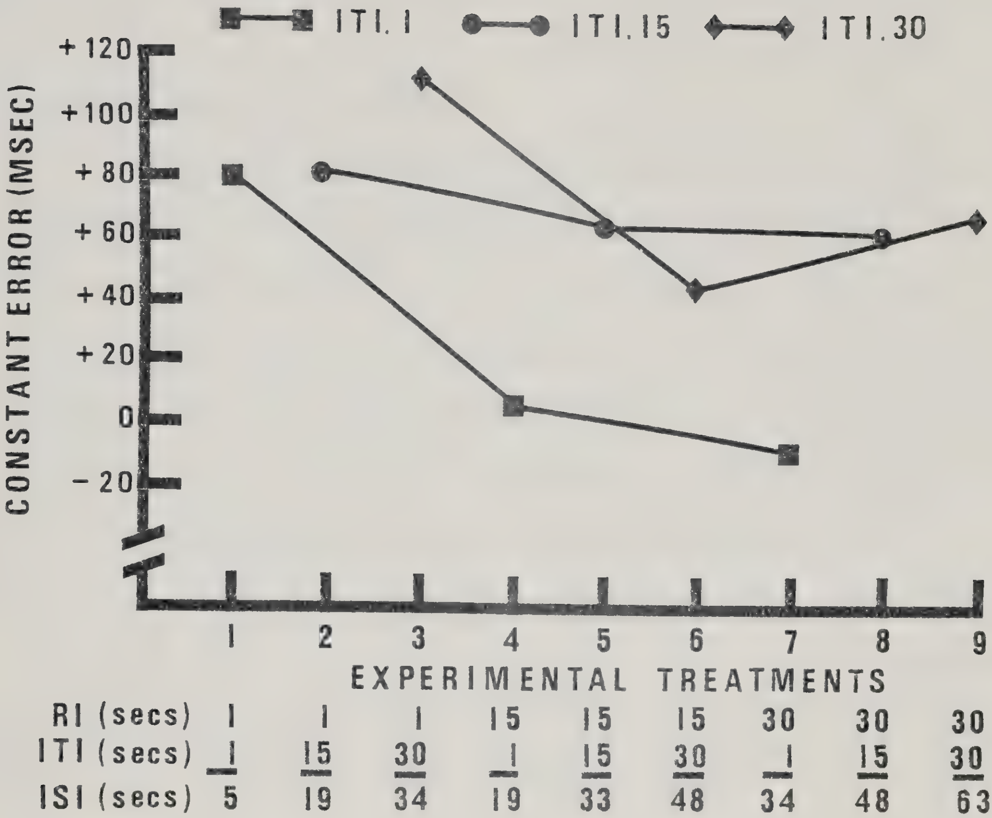


Figure 22 Mean constant error (CE) for the 1 second time length as a function of the experimental treatments (RI = retention intervals; ITI = inter-trial intervals; ISI = inter-stimulus intervals)

a one second intertrial interval.

Subjective Time Unit (STU)

The mean average performance and variable error of STU recalled by all subjects for the one second time length were 1.9 and 0.6 units, respectively. Subjects demonstrated a very strong stability for both dependent measures within all experimental conditions (see Table 13). A coefficient of variation (variable error divided by average performance) of 11.65% was obtained for the one second time length. The calculation of a coefficient of variation was performed in order to see if the relative variability (Weber fraction) remained constant over the various time lengths of the present study.

Discussion

The present findings provided no support to state that PI effects were operating in temporal STM for the one second time length. The lack of PI over trials and retention intervals was not related to the intertrial intervals; even when the intertrial intervals in the present investigation were shortened to one second, PI could not be demonstrated. A particular trend was observed for the one second duration under the CE scores when ISI increase. The one second intertrial interval produced better

Table 13

The means Average Performance and
Variable Error of subjective Time Units for the
One, Four and Eight seconds Time Lengths

		Intertrial Intervals[a]			
1 SECOND		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals[b]	R.1	1.8[c](0.6)[d]	1.9(0.7)	1.9(0.6)	1.9(0.6)
	R.15	1.8(0.6)	1.8(0.6)	1.8(0.7)	1.8(0.6)
	R.30	1.8(0.6)	1.9(0.3)	1.9(0.6)	1.9(0.5)
	MEAN	1.8(0.6)	1.9(0.5)	1.9(0.6)	1.9(0.6)
4 SECONDS		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	5.4(2.1)	5.3(1.7)	5.4(2.0)	5.4(1.9)
	R.15	5.4(2.0)	5.4(1.7)	4.9(1.3)	5.2(1.7)
	R.30	4.8(1.3)	5.1(1.7)	4.9(1.3)	4.9(1.4)
	MEAN	5.2(1.8)	5.3(1.7)	5.1(1.5)	5.2(1.7)
8 SECONDS		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	10.4(3.6)	10.3(3.7)	10.4(3.5)	10.4(3.6)
	R.15	10.4(3.5)	10.2(3.4)	10.2(3.5)	10.3(3.5)
	R.30	10.2(3.5)	10.2(3.5)	10.1(3.5)	10.2(3.5)
	MEAN	10.3(3.5)	10.2(3.5)	10.2(3.5)	10.3(3.5)

[a] ITI.1 = 1 second
ITI.15 = 15 seconds
ITI.30 = 30 seconds

[b] R.1 = 1 second
R.15 = 15 seconds
R.30 = 30 seconds

[c] Average performance
[d] Variable error

results than the 15 or 30 seconds intertrial intervals.

Similarities between the retention characteristics of the present study and those obtained in Experiment 4 were the following. In terms of CE and AE scores, there were no differences between the various retention intervals. The present study revealed no increase in variability as retention intervals increase. The latter result could be attributed to an experimenter-defined rehearsal as opposed to a subject-defined rehearsal used in Experiment 4. The present results under an experimenter-defined rehearsal, for all dependent measures, were quite similar to the results obtained in Experiment 5 under a similar rehearsal condition.

Retention abilities were demonstrated for all dependent measures when subjects used approximately two STU to time-fill the one second duration. Subjects were more accurate and less variable under a mental counting cognitive strategy than the subjects of Experiment 6 under a conscious time estimation cognitive strategy.

Four Seconds Time Length

Constant Error (CE)

All main effects and interactions for CE scores were not found to be significant ($p > .05$).

Subjects tended to underestimate the four seconds time length with an average error of -139 milli-

seconds. The results failed to provide support for the presence of interference and decay of interference. The CE scores for the four seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 14.

Absolute Error (AE)

All main effects and interactions for AE scores were not found to be significant ($p > .05$).

Subjects estimated the four seconds time length with an average error of 304 milliseconds. The results also failed to provide support for the presence of interference and decay of interference. The AE scores for the four seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 14.

Variable Error (VE)

A significant effect for VE, $F\ (2,34) = 3.49$, $p < .05$, was found for retention intervals. A Scheffé's test ($p < .05$) on the retention intervals' main effect was run. No meaningfull differences were obtained at that particular level. The main effect of intertrial intervals and the interaction between retention intervals and intertrial intervals did not reach the conventional level of significance ($p < .05$).

Table 14

The various Error Scores in Milliseconds for the Four seconds Time Length as a function of Retention Intervals and Intertrial Intervals

		Intertrial Intervals[a]			
CONSTANT ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals[b]	R.1	- 201	- 149	- 95	- 148
	R.15	- 160	- 43	- 90	- 98
	R.30	- 196	- 190	- 123	- 170
	MEAN	- 186	- 127	- 103	- 139
ABSOLUTE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	326	274	242	281
	R.15	291	248	309	283
	R.30	389	353	305	349
	MEAN	335	292	285	304
VARIABLE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	250	251	237	246
	R.15	252	333	283	289
	R.30	306	287	302	298
	MEAN	269	290	274	278

[a] ITI.1 = 1 second
ITI.15 = 15 seconds
ITI.30 = 30 seconds

[b] R.1 = 1 second
R.15 = 15 seconds
R.30 = 30 seconds

Subjects estimated the four seconds time length with an average error of 278 milliseconds. The VE scores for the four seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 14.

Inter-Stimulus Interval (ISI)

For all dependent measures, an increase of ISI produced no particular trend.

Subjective Time Unit (STU)

The mean average performance and variable error of STU recalled by all subjects for the four seconds time length were 5.2 and 1.7 units, respectively. Subjects demonstrated a very strong stability for both dependent measures within all experimental conditions (see Table 13). A coefficient of variation of 7.20% was obtained for the four seconds time length.

Discussion

The present findings did not provide support for PI effects operating in temporal STM for the four seconds time length. The lack of PI over trials and retention intervals was not related to the intertrial intervals. Proactive interference could not be demonstrated even when

an intertrial interval one second long was used. The subjects' estimated did not produce any particular trend with an increase of ISI for all dependent measures.

Similarities between the retention characteristics of the present study and those obtained in Experiment 4 were the following. Relative to CE and AE scores, there were no differences between the various retention intervals. In terms of VE, the present study revealed no increase in variability as retention intervals increased. Again, the latter result could be due to an experimenter-defined rehearsal used in the present investigation as opposed to a subject-defined rehearsal utilized in Experiment 4. The present results, under an experimenter-defined rehearsal and all dependent measures, were quite similar to the results obtained in Experiment 5 under a similar rehearsal condition.

Retention abilities were demonstrated for all dependent measures when subjects used approximately five STU to time-fill the four seconds duration. Subjects cf the present study were more accurate and less variable under a mental counting cognitive strategy than the subjects of Experiment 6 using a conscious time estimation cognitive strategy for all performance measures.

Eight Seconds Time Length

Constant Error (CE)

All main effects and interactions for CE scores were not found to be significant ($p > .05$).

Subjects tended to underestimate the eight seconds time length with an average error of -278 milliseconds. The results do not support the presence of interference or the decay of interference. The CE scores for the eight seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 15.

Absolute Error (AE)

All main effects and interactions for AE scores were not found to be significant ($p > .05$).

Subjects estimated the eight seconds time length with an average error of 608 milliseconds. Again, the results failed to provide support for the presence of interference or decay of interference. The AE scores for the eight seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 15.

Variable Error (VE)

The main effects of retention intervals and intertrial intervals, and the interaction between retention

Table 15

The various Error Scores in Milliseconds for the Eight seconds Time Length as a function of Retention Intervals and Intertrial Intervals

		Intertrial Intervals[a]			
CONSTANT ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals[b]	R.1	- 319	- 352	- 397	- 356
	R.15	- 414	- 323	- 159	- 299
	R.30	- 112	- 246	- 179	- 179
	MEAN	- 282	- 307	- 245	- 278
ABSOLUTE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	614	670	668	651
	R.15	739	649	517	635
	R.30	572	566	478	539
	MEAN	642	628	554	608
VARIABLE ERROR		ITI.1	ITI.15	ITI.30	MEAN
Retention intervals	R.1	378	339	326	348
	R.15	369	415	431	405
	R.30	338	397	401	379
	MEAN	362	384	386	377

[a] ITI.1 = 1 second
ITI.15 = 15 seconds
ITI.30 = 30 seconds

[b] R.1 = 1 second
R.15 = 15 seconds
R.30 = 30 seconds

intervals and intertrial intervals did not reach the conventional level of significance ($p < .05$).

Subjects estimated the eight seconds time length with an average error of 377 milliseconds. The VE scores for the eight seconds time length as a function of retention intervals and intertrial intervals are summarized in Table 15.

Inter-Stimulus Interval (ISI)

Increasing ISI produced no particular trend for all dependent measures.

Subjective Time Unit (STU)

The mean average performance and variable error of STU recalled by all subjects for the eight seconds time length were 10.3 and 3.5 units, respectively. Subjects demonstrated a very strong stability for both dependent measures within all experimental conditions (see Table 13). A coefficient of variation of 4.88% was obtained for the eight seconds time length.

Discussion

The present findings do not support the presence of PI operating in temporal STM for the eight seconds time length. The lack of PI over trials and retention intervals

was not related to the intertrial intervals. Proactive interference could not be demonstrated even when the intertrial interval was only one second long. Increasing ISI had no particular effect for all dependent measures.

Retention abilities were demonstrated for all dependent measures when subjects used approximately ten STU to time-fill the eight seconds duration. Subjects in the present study were more accurate and less variable under a mental counting cognitive strategy than the subjects of Experiment 6 using a conscious time estimation cognitive strategy for all performance measures.

General Discussion

The present findings under mental counting cognitive strategy for the one, the four and the eight seconds time lengths provided no support that PI effects were operating in temporal short-term memory (TSTM). The lack of PI was not due to the intertrial intervals. Proactive interference could not be demonstrated with a one second intertrial interval. The absence of PI could be ascribed to the following reasons: (a) the experimental conditions did not produce any PI effects, (b) PI effects were operating but were not detectable, and (c) PI effects were produced but due to the experimental procedures a release of PI occurred. The first of those three reasons seems to

be more appropriate for the present study.

The retention characteristics of the present study are quite similar to those found for verbal (Melton, 1963; Peterson and Peterson, 1959) and motor (Alain, 1974; Laabs, 1973) materials. The similarity was the result of the instructions given to the subjects. As opposed to a subject-defined rehearsal used in Experiment 4, an experimenter-defined rehearsal was utilized in the present investigation. The subjects were asked to use overt rehearsal and were told that the memory of a time length under a mental counting cognitive strategy implies that they retain a 'number' of STU as well as the 'length' of the STU (counting rate) (Vroon, 1976). Differences between the various retention intervals were not demonstrated for all dependent measures under such instructions. Although the present results give no evidence that the 'length' of the STU was remembered, it may be concluded that when subjects were told to pay attention to both variables, they retained time lengths of one, four and eight seconds in a similar fashion.

The one second was the only time length affected by an increase of ISI. The particular trend observed was that the subjects' estimates became less accurate (CE) as ISI increased. If accurate results are to be obtained in time estimation studies, short intertrial intervals should be utilized under the one second time length.

The present results, within the range of time lengths used, indicate that mediated (mental counting) time estimation variability increases when the mean estimate increases. The variability does not remain a relatively constant proportion of the mean as was the case in Davis' (1962) study and Experiment 6 (see Figure 23). The relative variability (Weber fraction) in Davis' (1962) study remained constant for time lengths of 2 to 8 seconds and with a rate of counting of two STU per second. These opposite results could be explained by the different procedures used in both studies. An experimenter-paced mental counting condition was used in Davis' (1962) study as opposed to a personal or self-paced mental counting in the present study. The present results demonstrated that the coefficients of variation (coefficients of proximity) were smaller than the ones obtained in Experiment 6 under a conscious time estimation cognitive strategy. Personal tempo is a very important attribute in temporal behavior and also in motor behavior (Smoll, 1975). The number of STU used in the present study was not the same from one subject to another and from one time length to another. Further experimental attention should be devoted to exploration of the nature of personal tempo and its role in temporal and motor behavior.

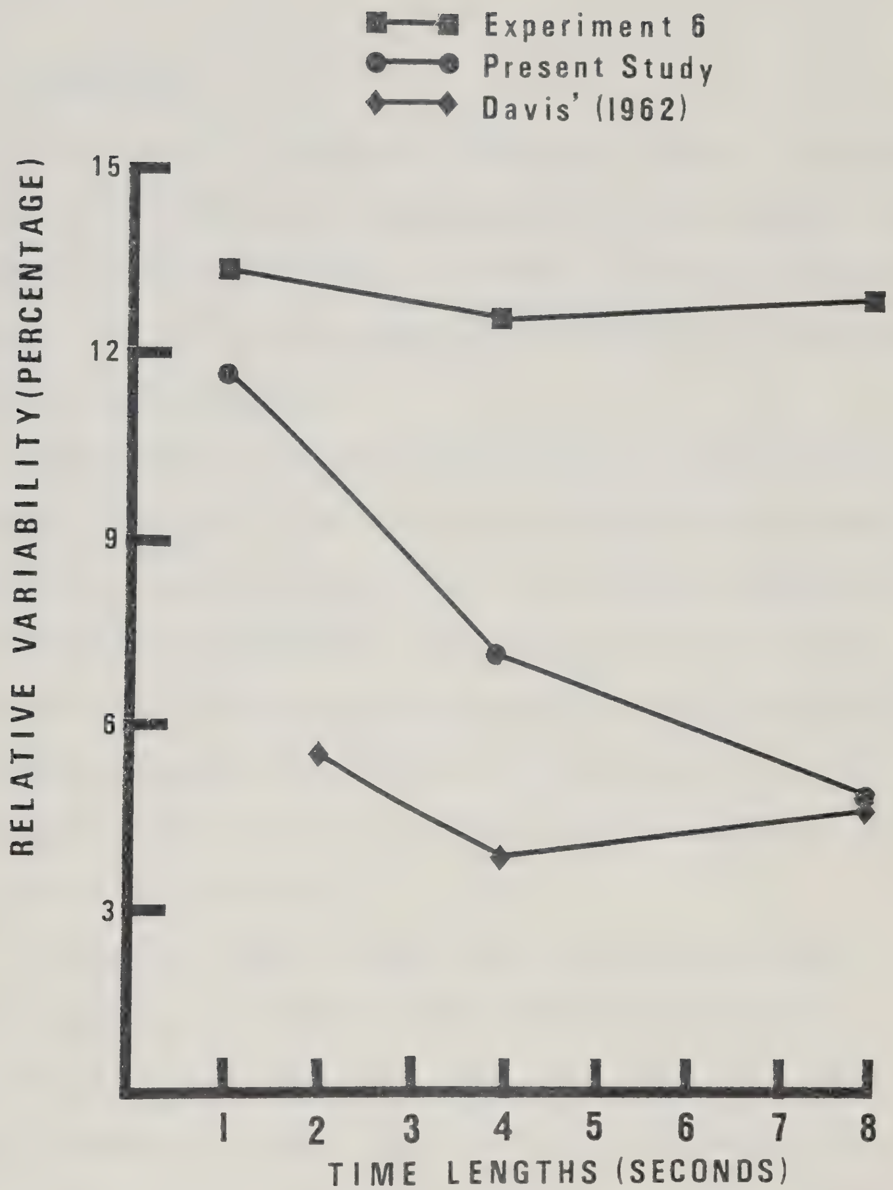


Figure 23 Mean relative variability for the various time lengths of the present study, Davis' (1962) study and Experiment 6

Summary of Section 3

The general purpose of Section 3 was to determine the causes of forgetting in temporal short-term memory under conscious time estimation and mental counting cognitive strategies. Proactive interference and rehearsal were the two processes investigated.

The loss of temporal information in short-term memory under conscious time estimation cognitive strategy for short time lengths was not due to proactive interference or rehearsal processes. Time lengths greater than four seconds under such cognitive strategy seem to follow a trace decay explanation. Again the results, as in Section 2, support the notion of a time length constraint on temporal short-term memory.

Proactive interference under mental counting cognitive strategy and short time lengths was not the process leading to a loss of temporal information. The rehearsal process, however, was the factor of importance causing forgetting of temporal information. When subjects were under an experimenter-defined rehearsal and specific instructions, no forgetting of temporal information was denoted. Overt rehearsal was the experimenter-defined rehearsal. The specific instructions were that the subjects should retain a 'number' of subjective time units

as well as the 'length' of the subjective time unit (counting rate) under mental counting cognitive strategy.

It appears, therefore, that some of the forgetting in temporal short-term retention must not be attributed to interference from previous trials (PI), but to factors other than interference (decay). Perhaps forgetting of temporal material could be ascribed to interference among items presented on a given trial (structural interference). The following section will investigate structural interference on temporal short-term memory under conscious time estimation and mental counting cognitive strategies.

Section 4

General Purpose of Section 4

The general purpose of Section 4 (Experiments 8, 9 and 10) was the investigation of structural interference (i.e. related interpolated task). The reasons to distinguish between the causes of decrements in recall due to unrelated and related interpolated tasks were as follows. When information enters short-term memory it assumes some kind of psychological structure and, if it is to be maintained, some or all of the limited processing capacity must be devoted to attending to or rehearsing that information. An attention-demanding interpolated task (i.e. unrelated interpolated task) was used in Experiments 2 and 4. There may also be an additional cause of interference depending on the nature of interpolated task. If this task, when entering short-term memory, takes the same psychological structure as the tbri structural interference occurs and recall of the tbri is hindered. The study of interference in temporal short-term memory of the structural type was investigated in the following experiments. The factors governing this interference will be described if such interference occurs.

The effects of temporal interpolated activities on temporal short-term memory were examined in Experiment 8.

Experiment 8

Structural Interference

and

Retention of Time

Temporal information under conscious time estimation and mental counting cognitive strategies appears to have different retention characteristics. Temporal information for time lengths greater than 4 seconds under conscious time estimation cognitive strategy is rapidly lost as a function of a rest period, and further, removal of subjects' attention during the retention interval, does not hinder recall performance any more than a simple rest (Experiments 2, 3 and 6). Similarly, temporal information for short time lengths under a mental counting cognitive strategy is lost quite rapidly over a very short time rest interval (Experiment 4). Further, when a subject's attention is completely occupied by having him indulge in a verbal interpolated task during the retention interval, recall performance will not be affected more than by a simple rest (Experiment 4). However, under a mental counting cognitive strategy and with appropriate instructions, subjects in Experiment 7 demonstrated no loss of temporal information after a rest interval.

The irrelevance of the material (verbal interpolated activity) used by the subjects during the retention intervals in Experiments 2 and 4 might be one of the reasons for the absence of an interference effect. One could question what kind of interpolated tasks might interfere

with the retention of time. For example, would material (temporal interpolated activity) which is more relevant and more similar (structural interference) to the criterion produce interference on the to-be-remembered item (tbri)?

The purpose of the following experiment was to investigate the effect of temporal interpolated activities on temporal short-term memory of time lengths of one and four seconds, reproduced under two forms of cognitive strategy; namely, conscious time estimation and mental counting.

Method

Subjects

Eight volunteer graduate students in physical education at the University of Alberta were used in this experiment.

Apparatus and Task

The apparatus and the task were the same as those described in Experiment 2 with the addition of the following apparatus.

The five levels of temporal interpolated activity described below were introduced after the operation of two decade interval timers (Hunter 111-C and 100-C). These timers were connected to a tone generator (Eico 377), amplifier and speaker. When the circuit controlling the

criterion time length had cycled through its pre-set time length, an audible tone was provided to the subjects 0.5 second after the pre-set time length. Following the tone, the subjects again depressed the left trigger in a squeeze-then-release manner to obtain another time length which acted as the temporal interpolated activity. Then the subjects were asked by the experimenter to reproduce either the first time length (criterion) or the second time length (temporal interpolated activity). The latter was a catch trial situation. The instruction by the experimenter was approximately of one second's duration.

Design

Five levels of temporal interpolated activity: (a) 60% (IT.1), (b) 80% (IT.2), (c) 100% (IT.3), (d) 120% (IT.4), and (e) 140% (IT.5) of the criterion time length were used. These five levels were combined factorially in a treatment by subjects' design with two levels of cognitive strategy: (a) conscious time estimation (CTE), and (b) mental counting (MC); and two levels of criterion time length, namely 1 and 4 seconds. Thus, for the 1 second time length, the five levels of temporal interpolated activity were: 0.6, 0.8, 1.0, 1.2 and 1.4 seconds; and for the 4 seconds time length they were 2.4, 3.2, 4.0, 4.8 and 5.6 seconds. Five trials were given for each of the 20 treatments.

Procedure

The subjects were given a number of trials to familiarize themselves with the equipment and the demands of the task. They attended one session of approximately 60 minutes. Four series of 25 trials each were assigned to each subject during the session. Each series was a combination of one level of cognitive strategy with one level of time length. Four treatment conditions (two cognitive strategies by two criterion time lengths) were assigned to 4 subjects, with the order of occurrence determined by a random 4 X 4 Latin Square. The other 4 subjects used the reverse of the same random 4 X 4 Latin Square. For the former 4 subjects, under a level of time length and a level of cognitive strategy (25 trials), a random 5 X 5 Latin Square was used for the interpolated levels while the reverse of the same random 5 X 5 Latin Square was utilized by the latter 4 subjects. Five catch trials were introduced and included in each series of 25 trials, one catch trial for each temporal interpolated activity. Ascending (former 4 subjects) and descending (latter 4 subjects) order catch trials were used according to the levels of temporal interpolated activity.

The following instructions were read to each subject: (a) the subject was asked to be as accurate as possible, (b) the subject was asked to express and demonstrate his understanding of the task, (c) the subject was told that he would hear the experimenter call out a number,

"one" or "two" after the presentation of the second time length in a trial. When the experimenter said "one", the subject was asked to make a recall equal in length to the first presentation (criterion) and when the experimenter said "two", the subject was asked to make a recall equal in length to the second presentation (interpolated activity stimulus), (d) the subject was asked not to use any time-aiding technique at any time (conscious time estimation) unless asked to do so. The experimenter explained thoroughly what was meant by a time-aiding technique, giving examples of the various kinds, (e) the subject was asked to use mental counting as his cognitive strategy (counting to himself) when asked to do so. The experimenter explained thoroughly what was meant by mental counting, and (f) the subject was asked to wait until the experimenter said "ready" before the beginning of the next trial.

Data Analysis

The dependent variables used were: (a) average (mean) performance (AP), (b) absolute error (AE), (c) signed constant error (CE), and (d) variable error (VE).

Results

Time Length

When average performance was analyzed, the subjects were able to maintain their estimates of one and

four seconds as distinct events over experimental conditions, F (1,7) = 400.03, $p < .01$. This suggests that when errors arose they were not due to the subjects confusing the two time lengths in memory.

A significant effect of time length, F (1,7) = 38.56, $p < .01$, was found for variable error. Subjects were more variable in their estimates of four seconds than one second. However, an interaction between time length and cognitive strategy occurred in the variable error analysis, F (1,7) = 7.41, $p < .05$. As illustrated in Figure 24, the interaction effect was almost totally due to the four seconds time length when held in memory under a mental counting cognitive strategy.

The main effect of time length was not significant ($p > .05$) for either the absolute error or constant error scores. A three factor interaction (time length by cognitive strategy by temporal interpolated activity) occurred in the absolute error analysis, F (4,28) = 3.2, $p < .05$.

Cognitive Strategy

A significant effect of cognitive strategy, F (1,7) = 7.74, $p < .05$, was found for variable error. Because of the significant time length by cognitive strategy interaction noted earlier, a Scheffé's test ($p < .05$) was run on the simple main effect. The significant difference

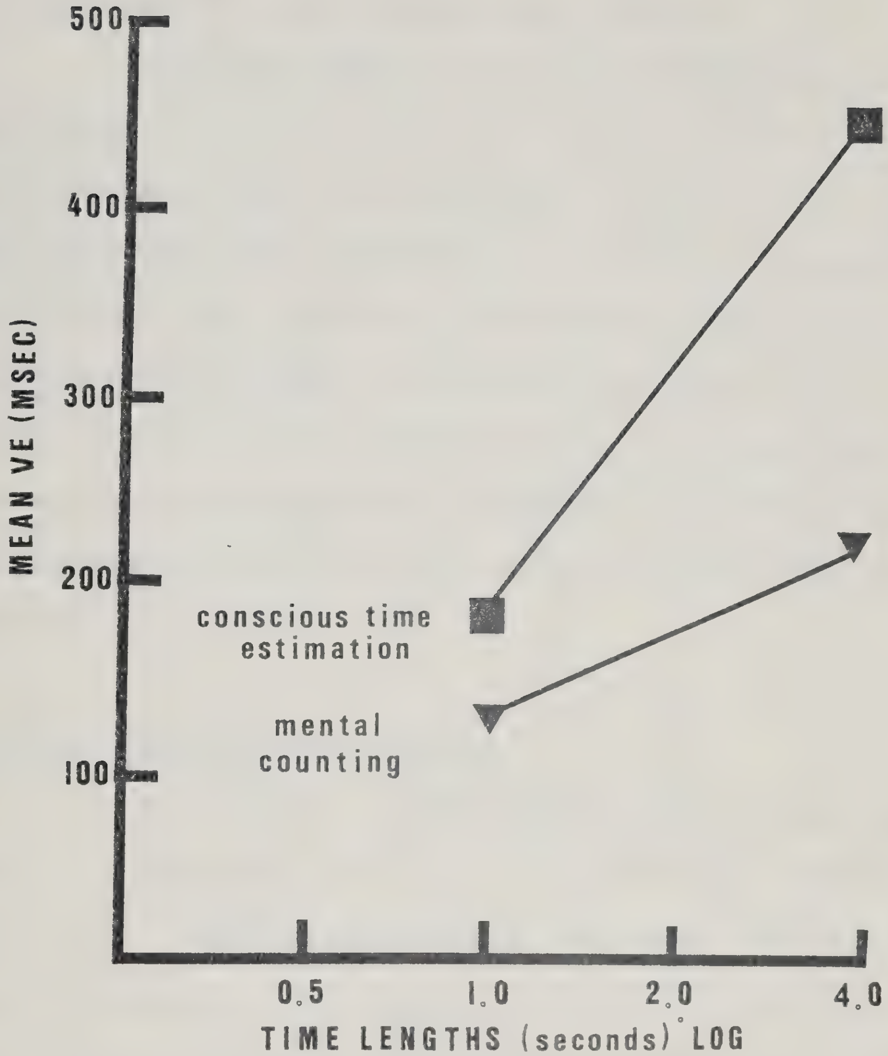


Figure 24 Mean variable error (VE) for conscious time estimation and mental counting cognitive strategies as a function of time lengths (1 and 4 seconds)

was noted between conscious time estimation and mental counting for the four seconds time length.

The main effect of cognitive strategy was also significant, $\underline{F}$ (1,7) = 6.72, $\underline{p} < .05$, for absolute error. Subjects were less accurate under conscious time estimation than they were when using mental counting. Because of the significant time length by cognitive strategy by temporal interpolated activity interaction noted earlier, a Scheffé's test ($\underline{p} < .05$) was run on the simple main effect. The significant meaningful difference was between conscious time estimation and mental counting for the four seconds time length.

Temporal Interpolated Activity

The temporal interpolated activity main effect was not significant for any of the dependent measures ($\underline{p} > .05$). When reproducing a one second time length under conscious time estimation or mental counting, subjects did not show any lengthening or shortening effects over all temporal interpolated activities with retention intervals of 2.1 to 2.9 seconds. A similar statement could be made for the four seconds time length and both cognitive strategies with retention intervals of 3.9 to 7.1 seconds.

The means of the various error scores for all cognitive strategies, time lengths and temporal interpolated activities are summarized in Table 16.

Table 16

Mean VE, AE, AP and CE in Milliseconds for
Cognitive Strategy, Time Length
and Temporal Interpolated Activity

Cognitive Strategy[a]	Time Length	Temporal Interpolated Activity[b] IT.1	IT.2	IT.3	IT.4	IT.5
		Variable Error (VE)				
MC	1 second	101	130	115	159	129
	4 seconds	184	214	206	243	268
CTE	1 second	262	192	162	144	167
	4 seconds	465	438	374	506	475
		Absolute Error (AE)				
MC	1 second	187	199	199	190	190
	4 seconds	215	271	206	262	332
CTE	1 second	422	403	288	363	339
	4 seconds	598	599	753	654	627
		Average Performance (AP)				
MC	1 second	1163	1165	1092	1138	1139
	4 seconds	3986	4026	4046	4076	4085
CTE	1 second	1333	1361	1230	1331	1300
	4 seconds	4152	4022	4219	4232	4115
		Constant Error (CE)				
MC	1 second	163	165	91	138	139
	4 seconds	- 15	25	46	76	84
CTE	1 second	333	361	230	331	300
	4 seconds	152	22	219	232	115

[a] MC = Mental counting
CTE = Conscious time estimation

[b] IT.1 = 60% of the criterion time length
IT.2 = 80% of the criterion time length
IT.3 = 100% of the criterion time length
IT.4 = 120% of the criterion time length
IT.5 = 140% of the criterion time length

Catch Trial

When subjects had to reproduce the second stimulus length (temporal interpolated activity length), significant effects were found for average performance (AP) across the time lengths, F (1,7) = 712.75, $p < .01$, and across the temporal interpolated activities, F (4,28) = 279.50, $p < .01$. However, an interaction between time length and temporal interpolated activity occurred in the AP analysis, F (4.28) = 57.14, $p < .01$, (see Figure 25). Because of this interaction, a Scheffé's test ($p < .05$) was run on the simple main effect. Significant differences were obtained between all levels of temporal interpolated activity for the four seconds time length, and between IT.1 vs IT.3, IT.1 vs IT.4, IT.1 vs IT.5, IT.2 vs IT.4, IT.2 vs IT.5 for the one second time length.

The mean for average performance (AP) scores on the catch trials for all cognitive strategies, time lengths and temporal interpolated activities are summarized in Table 17.

Discussion

Time Length and Cognitive Strategy

In terms of the significant main effects and interaction effects noted earlier for absolute and variable error measurements, the following conclusions are of interest when the criterion time length was stored with

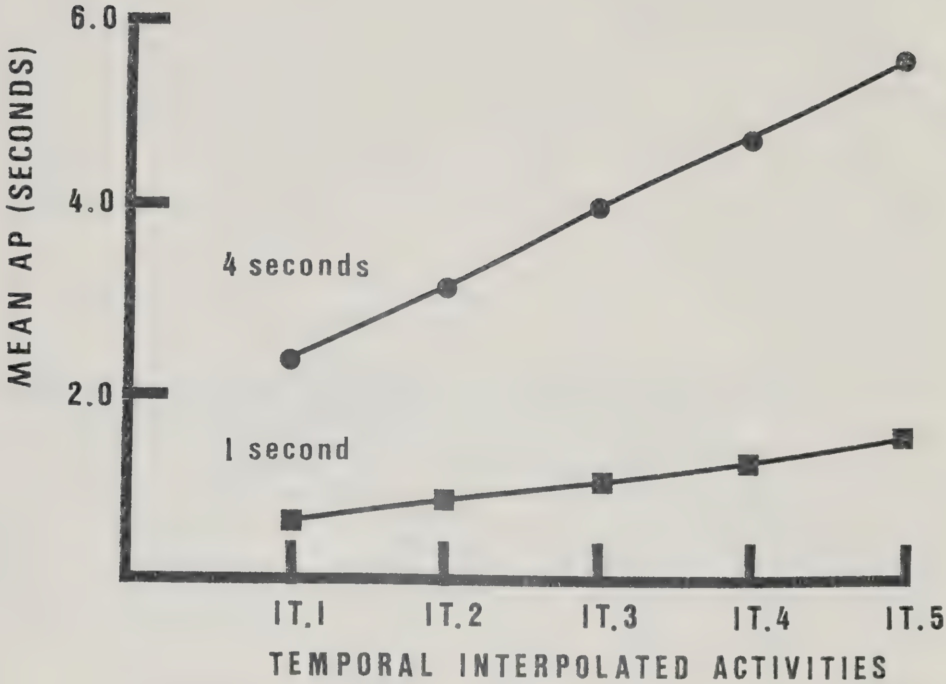


Figure 25 Mean average performance (AP) for time lengths of 1 and 4 seconds as a function of temporal interpolated activities (IT.1 = 60% of the criterion time length; IT.2 = 80% of the criterion time length; IT.3 = 100% of the criterion time length; IT.4 = 120% of the criterion time length; IT.5 = 140% of the criterion time length)

Table 17

Mean Average Performance in Milliseconds for Catch Trial under Cognitive Strategy, Time Length and Temporal Interpolated Activity

Cognitive Strategy[a]	Time Length	Temporal Interpolated Activity[b] IT.1	IT.2	IT.3	IT.4	IT.5
MC	1 second	554	864	1125	1250	1495
	4 seconds	2456	3122	3843	4739	5598
CTE	1 second	704	822	1138	1351	1414
	4 seconds	2348	3159	3875	4677	5406

[a] MC = Mental counting
CTE = Conscious time estimation

[b] IT.1 = 60% of the criterion time length
IT.2 = 80% of the criterion time length
IT.3 = 100% of the criterion time length
IT.4 = 120% of the criterion time length
IT.5 = 140% of the criterion time length

another duration: (a) subjects are less accurate and more variable as time lengths increase when reproducing under conscious time estimation, (b) subjects are more accurate and less variable when reproducing the four seconds time length under mental counting as compared to conscious time estimation, and (c) subjects holding a criterion time of one second in memory under mental counting are as accurate and variable as they are when they recall the to-be-remembered item under conscious time estimation. The present results with the exception of the latter conclusion in terms of variable error scores were obtained in Experiment 2 under an immediate retention interval and only one time length stored.

Temporal Interpolated Activity

The lack of significance for the main effect of temporal interpolated activity along with its non-significant interaction with the other factors for both absolute error and variable error suggests that subjects retain time lengths of one and four seconds in a similar fashion. Furthermore, when the present data (two time lengths presented at input) are compared with results of Experiments 2 and 4 (immediate retention interval and one time length presented at input), some observations can be made. When subjects hold the criterion time length of one second for a period of 2.1 to 2.9 seconds and the criterion time length

of four seconds for a period of 3.9 to 7.1 seconds under conscious time estimation, they were (for their respective time lengths) as variable as the subjects in Experiment 2 when they recalled the duration immediately. This is suggestive of the fact that the similarity of the stored material does not affect immediate recall performance in terms of variable error scores. Moreover, the results of the present study obtained under a mental counting cognitive strategy were similar to the variable error scores of Experiment 4 when the subjects were asked to recall immediately. However, in terms of absolute error (accuracy) the equivalence of the present results with those obtained with the immediate retention interval of Experiment 2 (conscious time estimation) or Experiment 4 (mental counting) is less evident for the one second time length although clearer for the four seconds time length. It seems that, for the one second time length, subjects are less accurate when two time lengths are stored than when one is stored under either cognitive strategy.

The structural interference (5 levels) used in the present study had no particular effect on the to-be-remembered item (tbri); the tbri was still available and recalled almost at a level of an immediate retention condition when compared with previous studies. Confusion seems to have occurred when the subjects stored two temporal lengths in memory for the present retention intervals. However, such speculation was not tested and, thus, remains

to be answered. One might question whether the storage capacity of the subjects can accommodate at least two temporal lengths. If so, we could conclude that the subjects were operating within the limits of their memory span. When two time lengths were presented to the subjects, both time lengths would be stored intact.

Perhaps, if two or more time lengths were presented as the temporal interpolated activities during the retention interval, interference would appear as a consequence of information load, or perhaps because of a central tendency or range effect between the various time lengths. Structural interference may also be demonstrated with retention intervals longer than the 2.9 seconds (one second time length) and the 7.1 seconds (four seconds time length) of the present study. The time-in-store factor, when two time lengths are stored together, remains to be investigated.

Catch Trials

Subjects, when asked to reproduce the temporal interpolated activity lengths, were able to differentiate the five levels used under the 4 seconds time length. However, for the one second time length, subjects confused some of the levels of temporal interpolated activity. Therefore if confusion in the recovery of the to-be-remembered item is to be prevented in future research, greater percentages of the criterion length under conscious time

estimation and mental counting should be used for the one second time length in order to assent the distinctness problem.

A number of questions were raised in Experiment 8. Firstly, what is the effect of the time-in-store factor when two time lengths are stored together at input? Secondly, could a second time length be loaded into memory without interfering with another time length already in store? These two factors were investigated in Experiment 9.

Experiment 9

Time-in-Store, Similarity and Retention of Time under Conscious Time Estimation

The time-in-store factor when only one time length was stored under conscious time estimation was studied in Experiments 2 and 3. It was demonstrated that the four seconds time length was lost quite rapidly over a very short rest interval (15 seconds) and that the one second time length was not affected more by a similar period of rest than with an immediate recall.

When two time lengths were stored together under conscious time estimation in Experiment 8, it was proposed that the similarity of the stored material does not affect immediate recall performance. Such a suggestion was provided when the results of Experiment 8 were compared with those of Experiment 2. However, an immediate retention interval was not included in Experiment 8 and, as a result, one might question the validity of those observations. Thus, such a retention interval was used in the present investigation.

Furthermore, if two time lengths are stored together, an interference effect (structural interference) may be more apparent after a delay interval than with immediate recall. If the similarity of the material does not influence temporal recall, perhaps the time-in-store may be an important factor.

Consequently, in terms of the results of Exper-

iment 8, the present study was designed to: (a) determine whether the immediate reproduction of a time length changes if, at input, a temporal-interpolated duration is presented just prior to or just after the criterion time length, (b) determine whether a temporal-interpolated duration affects recall performance of a criterion time length when both are held in store for a period of 15 seconds, and (c) determine whether the subject's recall performance for a particular time length is the same when the time length to be recalled is presented first as when it is presented second (order effect). In the present investigation the subjects were tested under a conscious time estimation cognitive strategy.

Method

Subjects

Eight volunteer subjects in physical education at the University of Alberta were used in this experiment.

Apparatus and Task

The apparatus and the task were the same as those described in Experiment 2 when the input consisted of only one time length. When two time lengths were stored at input, two additional decade interval timers (Hunter 111-C and 100-C) were used. These timers were connected to a tone generator (Eico 377), amplifier and speaker. When the

circuit controlling the first time length had cycled through its pre-set time length, an audible tone was provided to the subjects one second after the pre-set time length. Following the tone, the subjects again depressed the left trigger in a squeeze-then-release manner in order to obtain the second time length. Then the subjects were asked by the experimenter to reproduce immediately or after a period of 15 seconds either the first or the secone time length. In order to ensure that the subjects stored both time lengths for the purpose of recall, a post-cuing procedure was used. When the subjects had to reproduce after a retention interval of 15 seconds, a tone indicated the end of the interval. The circuit used for the production of the first audible tone which preceded the second time length was used again in order to signify the end of the rest period.

Design

Four levels of retention interval were used: (a) immediate recall (1 second) of the criterion time length when only one time length was presented at input (IM.1), (b) immediate recall (1 second) of one of two time lengths presented at input (IM.2), (c) recall of the criterion time length after 15 seconds of rest when only one time length was presented at input (R.1), and (d) recall of one of two time lengths presented at input after 15 seconds of delay (R.2). These four levels were combined

factorially in a treatment by subjects' design with two levels of time length: (a) one second, and (b) four seconds (see Table 18). Six trials were given for each of the 8 treatments.

Pairing

For two of the retention interval levels the input consisted of two time lengths presented successively. The pairing of these two time lengths was done as follows. Two durations were used (1 and 4 seconds) and two pairs were created, namely, 1-4 and 4-1. Each pair was repeated six times in order to obtain 12 pairs, one per trial. Further, for both the 1-4 and 4-1 pairings, the subjects reproduced the one second time length on three of the six trials and the four seconds time length on the remaining three trials. Thus, each subject reproduced each time length a total of six times.

Recall Period

The recall periods for the one and four seconds time lengths, as in Experiment 6, under the IM.1 and R.1 retention intervals were of 2 and 6 seconds, respectively. The recall periods for the one and four seconds time lengths under the IM.2 and R.2 retention intervals were of 4 and 8 seconds, respectively.

Table 18

Retention Conditions (4) for the
One and Four seconds Time Lengths

Retention Conditions[a]	IM.1		IM.2		R.1		R.2	
Time length in seconds (TL)	1	4	1-4 or 4-1		1	4	1-4 or 4-1	
Period in seconds between two time lengths (P)			1	1			1	1
Retention interval in seconds (RI)	1	1	1	1	15	15	15	15
Recall period in seconds (RP)	2	6	4	8	2	6	4	8
Intertrial interval in seconds (ITI)	26	19	19	15	22	15	15	11
Inter-stimulus interval in seconds (ISI)[b]	30	30	30	30	40	40	40	40

[a] IM.1 = Immediate recall
IM.2 = Immediate recall when both criterion duration and interpolated duration were stored
R.1 = Recall after 15 seconds
R.2 = Recall after 15 seconds when both criterion duration and interpolated duration were stored

[b] ISI for IM.1 and R.1 = 

ISI for IM.2 and R.2 = 

Procedure

The subjects were given a number of trials to familiarize themselves with the equipment and the demands of the task. They attended one session of approximately 40 minutes. Each subjects was given 48 trials during the session. Four series of 12 trials each were assigned to each subject during the session with a two minutes rest between each series. Each series was a combination of one of the levels of retention interval with both levels of time length. The four levels of retention interval were assigned to four subjects with the order of occurrence determined by a 4 X 4 balanced Latin Square. The other four subjects used the same 4 X 4 balanced Latin Square. In each series, the subjects recalled the one second time length on six trials and the four seconds time length on another six trials. Within each series an intertrial interval was used (see Table 18). According to the results obtained in Experiment 6, the intertrial intervals could occur within a period of time from 1 to 30 seconds. When the subjects were under the IM.1 and R.1 retention interval conditions, the one (6 trials) and four (6 trials) seconds time lengths were randomly assigned to the subjects within each series. On the other hand, when the subjects were under the IM.2 and R.2 retention interval conditions, the 12 pairs (see Pairing) were randomly assigned to the subjects within each series.

The following instructions were read to each

subject: (a) the subject was asked to be as accurate as possible, (b) the subject was asked to express and demonstrate his understanding of the task, (c) the subject was asked to concentrate (covert rehearsal) on the input (one or two time lengths) during the period of rest, (d) the subject was told that he would hear the experimenter call out a number, "one" or "two" after the presentation of two time lengths. When the experimenter said "one", the subject was asked to make a recall equal in length to the first presentation and when the experimenter said "two", the subject was asked to make a recall equal in length to the second presentation. This instruction was one second long, (e) the subject was asked not to use any time-aiding technique at any time. The experimenter explained thoroughly what was meant by a time-aiding technique, giving examples of the various kinds, and (f) the subject was asked to wait until he heard a sound before the beginning of the next trial.

Data Analysis

The dependent variables used were: (a) average (mean) performance (AP), (b) absolute error (AE), (c) signed constant error (CE), and (d) variable error (VE).

Results

Order of Responses

Four 4-way analyses of variance (time length by retention interval by order by subject) were conducted on the dependent variables: average performance, absolute, constant and variable error. The main factor of interest was the order of presentation of two different time lengths. The purpose of this analysis was to determine if subjects' recall performance of a particular time length was the same when the time length to be recalled was presented first as when it was presented second.

For this factor of interest, the analyses of variance yielded non-significant $\underline{F}$ values for average performance, absolute, constant and variable error scores. No interaction was observed in any one of those analyses. The data were therefore collapsed and four 3-way analyses of variance (time length by retention interval by subject) were calculated for average performance, absolute, constant and variable error.

Time Length

The mean (6 trials) estimates calculated for each treatment condition and each subject was termed average performance. The subjects were able to maintain their estimates of one and four seconds as distinct events over experimental conditions, $\underline{F}$ (1,7) = 98.74, $\underline{p} < .01$. This

suggests that when errors arose they were not due to the subjects confusing the two time lengths either perceptually or in memory. The interaction between time length and retention interval for average performance was not significant ($p > .05$).

The main effect of time length was found to be significant for both absolute error, F (1,7) = 14.15, $p < .01$, and variable error, F (1,7) = 28.39, $p < .01$. The subjects produced larger errors and were more variable in their estimates of the four seconds time length as compared to the one second time length. However, interactions between time length and retention interval occurred for absolute error, F (3,21) = 2.88, $p < .06$, and variable error, F (3,21) = 2.83, $p < .06$. The interaction effects were almost totally due to the four seconds time length when held in memory with the interpolated duration for 15 seconds (see Figures 26 and 27).

The subjects did not show any significantly consistent directional bias in their estimates of either one or four seconds. The usual development of a central tendency or range effect was not demonstrated. The time length by retention interval interaction for constant error was not significant ($p > .05$).

Retention Interval

A significant effect, F (3,21) = 3.90, $p < .05$, was found for absolute error across the retention intervals.

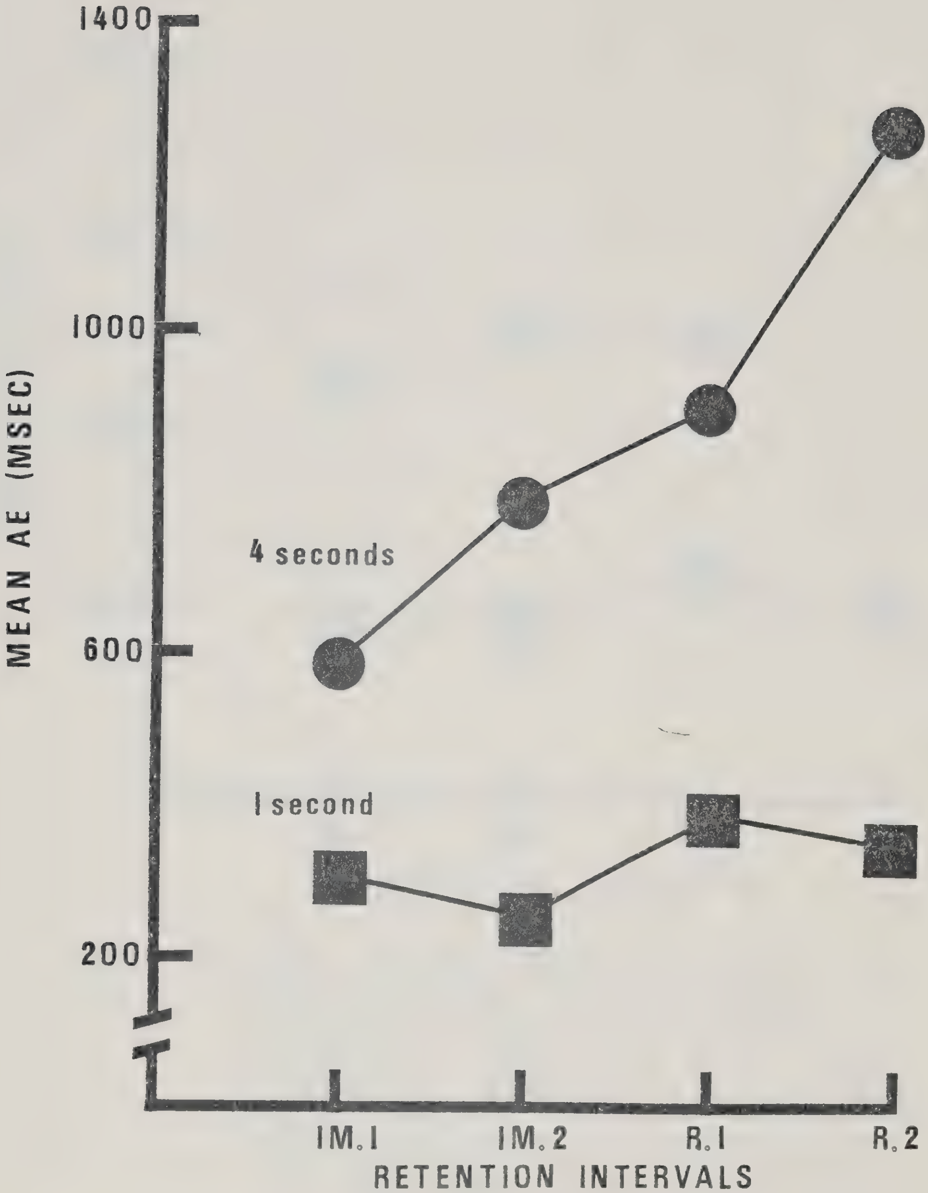


Figure 26 Mean absolute error (AE) for the 1 and 4 seconds time lengths as a function of the retention intervals (IM.1 = immediate recall; IM.2 = immediate recall when both criterion duration and interpolated duration were stored; R.1 = recall after 15 seconds; R.2 = recall after 15 seconds when both criterion duration and interpolated duration were stored)

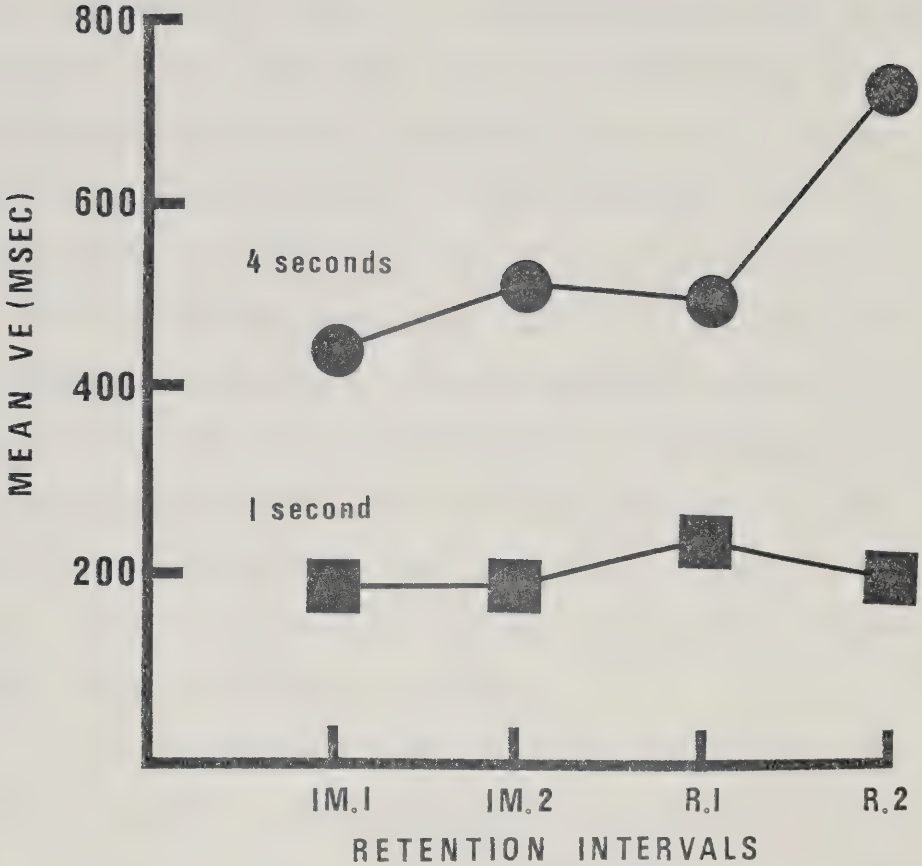


Figure 27 Mean variable error (VE) for the 1 and 4 seconds time lengths as a function of the retention intervals (IM.1 = immediate recall; IM.2 = immediate recall when both criterion duration and interpolated duration were stored; R.1 = recall after 15 seconds; R.2 = recall after 15 seconds when both criterion duration and interpolated duration were stored)

Because of the significant time length by retention interval interaction noted earlier, a Scheffé's test ($p \leq .05$) on the simple main effect was run. Significant differences were found between the following contrasts for the four seconds time length only. The immediate recall retention interval resulted in smaller errors than the recall after 15 seconds when both criterion duration and interpolated duration were stored retention interval. Immediate recall of the tbri when both criterion duration and interpolated duration were stored retention interval resulted in smaller errors than the recall after 15 seconds when both criterion duration and interpolated duration were stored retention interval.

Variable error scores analyzed across the retention intervals also resulted in a significant main effect, F (3,21) = 2.33, $p \leq .10$. The significant time length by retention interval interaction reported above resulted in the calculation of a second simple main effect using a Scheffé's test ($p \leq .05$). Significant differences were found between the following contrasts for the four seconds time length only. Immediate recall of the tbri resulted in less variability than the recall of the tbri after 15 seconds when two time lengths were stored at input. The immediate recall when both criterion duration and interpolated duration were stored retention interval was less variable than the recall after 15 seconds when both criterion duration and interpolated duration were stored

retention interval. The recall after 15 seconds retention interval was less variable than the recall after 15 seconds when both criterion duration and interpolated duration were stored retention interval.

Signed constant error scores did not produce significant main effect across retention intervals ($p > .05$). The F ratio for retention interval obtained from average performance measurements was not significant ($p > .05$). The various mean error scores for each condition of time length and retention interval are summarized in Table 19.

Discussion

Time Length and Retention Interval

The significant main effect of time length along with its significant interaction with retention interval for both absolute and variable error, suggests that subjects retain time lengths of one and four seconds differently. When subjects hold a criterion time length of four seconds in memory for a period of 15 seconds with an interpolated duration, they become less accurate and more variable than if they recall the item: (a) immediately, (b) immediately when both criterion duration and interpolated duration were stored, or if the item to be remembered is only one second long. Further, subjects were

Table 19

Mean VE, AE, AP and CE in Milliseconds for Time Length and Retention Interval

Time Length	Retention Interval[a]	VE	AE	AP	CE
1 second	IM.1	192	310	1264	264
	IM.2	199	250	1192	192
	R.1	241	370	1331	331
	R.2	212	329	1255	255
4 seconds	IM.1	438	566	3660	-340
	IM.2	508	780	3600	-400
	R.1	496	902	3688	-312
	R.2	735	1278	4055	55

a IM.1 = Immediate recall
IM.2 = Immediate recall when both criterion duration and interpolated duration were stored
R.1 = Recall after 15 seconds
R.2 = Recall after 15 seconds when both criterion duration and interpolated duration were stored

b VE = Variable Error
AE = Absolute Error
AP = Average Performance
CE = Constant Error

more variable when two time lengths were stored during a 15 seconds retention interval than an unfilled retention interval of 15 seconds for the four seconds time length.

Immediate Recall Performance

The immediate recall performance of the one second and/or the four seconds time length was not different when the criterion was stored with another time length. This is suggestive of the fact that the similarity of the stored material does not affect immediate recall performance. These results are similar to the data obtained in Experiment 8, although somewhat different from that found by Turchioe (1948). For time lengths of 0.78, 1.01 and 1.39 second, the latter study denoted difference between the immediate recall of one time length versus two time lengths retention intervals.

The Time-in-Store Factor: only One Time Length is Stored

The results of this study show that time-in-store was not a factor affecting the recall of temporal information. Indeed, when only the criterion time length (either the 1 second or the 4 seconds time length) was stored, recall performance after 15 seconds of rest was not statistically different from immediate recall performance for all dependent measures. Therefore, in this particular experiment time had no apparent effect on the recall of temporal information. This is not in accordance with the

results obtained in Experiments 2, 3 and 6 for the four seconds time length.

The Time-in-Store Factor: Two Time Lengths are Stored Together

In proposing his acid bath theory, Posner (1966) felt that time-in-store would enhance interference in that the information would decay over time-in-store and hence, would be more susceptible to interference. Applied to temporal information, this reasoning would predict that, if two time lengths were stored together, interference effects would be more apparent after a delay interval than at immediate recall.

The results of this study support Posner's implications for the four seconds time length. When two time lengths were stored together, the recall performance of the criterion time length after 15 seconds of rest differ from that of immediate recall for the absolute and variable dependent variables. Such results are indicative of the fact that time-in-store did activate interference between the stored items as would have been predicted from Posner's acid bath theory.

Although the analysis of constant error scores revealed nothing significant, it was interesting to note that when subjects recalled one of two time lengths immediately or after 15 seconds retention intervals, two opposing forms, assimilation and contrast were operating.

The former was denoted when subjects reproduced the four seconds time length immediately with an average error of -400 milliseconds (i.e. they underestimated). The latter was found when subjects recalled the four seconds time length after 15 seconds of rest with an average error of +55 milliseconds (i.e. they overestimated). The time-in-store factor was responsible for those two opposing effects.

Differential Effect of Time-in-Store when only the Criterion Time Length was Stored as Opposed to when Two Time Lengths were Stored

When two time lengths were stored together, time-in-store affected recall performance quite differently from when only the criterion time length was stored for the four seconds time length. A 15 seconds rest significantly affected recall performance when two time lengths were stored together as shown by increased absolute and variable errors at recall while the same retention delay had no effect on the recall of the criterion time length when only one time length was stored. Based on this evidence, one could be tempted to conclude that the acid bath model proposed by Posner is representative of the laws governing the loss of temporal information.

The systematic differences obtained could also be representative of the fact that the subjects used quite different strategies going from one condition to the other.

Such strategies were determined partly by the objective conditions of the experiment and partly by the attitude of the subjects. When only one time length was stored, the subjects had to operate on the basis of temporal information alone and consequently, the subjects retained the time length as well after 15 seconds retention interval as on immediate recall retention interval. Alternately, when two time lengths were stored together at input, the subjects had the opportunity to either operate on the basis of temporal information alone or on the basis of a differential judgment between the two time lengths that were presented. For instance the subjects could have used crude labels such as "the first one is the longer time length" and "the second one is the shorter time length". When asked to reproduce the first or the second time length stored, the subjects would make sure that the tbri he had identified as being longer was really longer. The results obtained when both time lengths were stored tend to support such an interpretation for the four seconds time length. It seems that subjects were operating on the basis of a differential judgment when they had to recall after 15 seconds. Subjects were capable of operating on the basis of temporal information when they reproduced immediately.

Another alternative could be that some verbalization was involved in all retention conditions. As was mentioned in Experiment 2, it may be possible that time

lengths are encoded verbally. If this is the case, the verbal codes when one time length was stored as opposed to the storage of two time lengths would be more meaningful. Less meaningful verbal codes such as "the first one is the longer time length" would carry more uncertainty for the reproduction of longer than short time lengths. Further, the uncertainty would be more noticeable after a certain period of time. The results of the present study tend to support also such an explanation.

Order of Responses

The results indicated that, when two time lengths were stored together, subjects' recall performance of the criterion time length was the same whether it was presented first or second. This implies that subjects' storage capacity could accomodate at least two time lengths. This verification was necessary to determine whether or not, in the successive presentation of the two time lengths, the second one could be stored intact. It can be concluded that subjects were operating within the limits of the memory span and when two time lengths were presented to the subjects, both time lengths were stored intact.

The purposes of Experiment 10 were the same as those in the latter experiment. However, in this study the subjects were asked to use mental counting as their cognitive strategy.

Experiment 10

Time-in-Store, Similarity and Retention of Time under Mental Counting

The time-in-store factor was studied in Experiment 4 with only one time length stored using a mental counting cognitive strategy. It was demonstrated that the one and four seconds time lengths were lost quite rapidly over a very short rest interval (15 seconds). However, in Experiment 7, such results were not found.

When two time lengths were stored together under mental counting in Experiment 8, it was proposed that the similarity of the stored material does not affect immediate recall performance. Such a suggestion was provided when the results of Experiment 8 were compared with those of Experiment 4. However, an immediate retention interval was not included in Experiment 8 and, as such, one might question the validity of those observations. Thus, in the present investigation such a retention interval was included.

Furthermore, if two time lengths are stored together, an interference effect (structural interference) may be more apparent after a delay interval than with immediate recall. If the similarity of the material does not influence temporal recall, perhaps the time-in-store may be an important factor.

Consequently, in terms of the results of Experiment 8, the present study was formed in order to:

(a) determine whether the immediate reproduction of a time length changes if, at input, a temporal-interpolated duration is presented just prior to or just after the criterion time length, (b) determine whether a temporal-interpolated duration affects recall performance of a criterion time length when both are held in store for a period of 15 seconds, and (c) determine whether the subjects' recall performance of a particular time length is the same when the time length to be recalled is presented first as when it is presented second. In the present investigation the subjects were using a mental counting cognitive strategy.

Method

Subjects

Subjects in Experiment 9 were used again in this experiment.

Apparatus, Task, Design, Pairing and Recall Period

The apparatus, the task, the design, the pairing and the recall periods were the same as those described in Experiment 9.

Procedure

The procedure was the same as that described in Experiment 9 with the following modifications. Instructions (c) and (e) in the procedure section of Experiment 9 were

now as follows: (c) the subjects were asked to rehearse (rote repetition) the criterion time length during the unfilled retention interval, and (e) the subjects were asked to use a mental counting cognitive strategy. The experimenter explained thoroughly what was meant by the latter. Moreover, the subjects were told that the memory of a time length under a mental counting cognitive strategy implies that they retain a 'number' of subjective time units as well as the 'length' of the subjective time unit (counting rate). The subjects were told to pay attention to both variables.

Data Analysis

The dependent variables used were the same as those in Experiment 9.

Results

Order of Responses

Four 4-way analyses of variance (time length by retention interval by order by subject) were conducted on the dependent variables: average performance, absolute, constant and variable error. The main factor of interest was the order of presentation of two different time lengths. The purpose of this analysis was to determine if subjects' recall performance of a particular time length was the same

when the time length to be recalled was presented first as when it was presented second.

For this factor of interest, the analyses of variance yielded non-significant F values for average performance, absolute, constant and variable error scores. No interactions were observed in any one of those analyses. The data were therefore collapsed and four 3-way analyses of variance (time length by retention interval by subject) were calculated for average performance, absolute, constant and variable error.

Time Length

The mean (6 trials) estimates calculated for each treatment condition and each subject were termed average performance. The subjects were able to maintain their estimates of one and four seconds as distinct events over experimental conditions, $F\ (1,7) = 478.48$, $p < .01$. This suggests that when errors arose they were not due to the subjects confusing the two time lengths either perceptually or in memory. The interaction between time length and retention interval for average performance was not significant ($p > .05$).

The main effect of time length was found to be significant for both absolute error, $F\ (1,7) = 11.63$, $p < .05$, and variable error, $F\ (1,7) = 18.50$, $p < .01$. The subjects produced larger errors and were more variable in their estimates of the four seconds time length when

compared to the one second time length. The interactions between time length and retention interval for absolute and variable errors were not significant ($p > .05$).

The main effect of time length was found to be significant for constant error, $F(1,7) = 7.84$, $p < .05$. Subjects overestimated the one second time length and underestimated the four seconds time length. The interaction between time length and retention interval for constant error was not significant ($p > .05$).

Retention Interval

The F ratio for retention intervals obtained from all dependent variables was not significant ($p > .05$). The various mean error scores for each condition of time length and retention interval are summarized in Table 20.

Discussion

The significant main effect of time length with the non-significant main effect of retention interval and their non-significant interaction for all dependent measures, propose that subjects retain time lengths of one and four seconds in a similar fashion. When subjects held criterion times of one or four seconds in memory for a period of 15 seconds with or without interpolated

Table 20

Mean VE, AE, AP and CE in Milliseconds for Time Length and Retention Interval

Time Length	Retention Interval[a]	Dependent Measure[b] VE	AE	AP	CE
1 second	IM.1	146	258	1183	183
	IM.2	140	189	1168	168
	R.1	177	239	1201	201
	R.2	149	297	1285	285
4 seconds	IM.1	257	280	3872	-128
	IM.2	323	497	3716	-284
	R.1	405	427	3907	- 93
	R.2	387	442	3978	- 22

[a] IM.1 = Immediate recall
IM.2 = Immediate recall (two time lengths at input)
R.1 = Recall after 15 seconds
R.2 = Recall after 15 seconds (two time lengths at input)

[b] VE = Variable Error
AE = Absolute Error
AP = Average Performance
CE = Constant Error

duration, they recalled the item as well as the immediate recall with or without interpolated duration.

Immediate Recall Performance

The immediate recall performance of the 1 second and/or the 4 seconds time length was not different when the criterion was stored with another time length. The similarity of the stored material did not affect immediate recall performance. These results are similar to the data obtained in Experiment 8.

The Time-in-Store Factor: only One Time Length is Stored

The results of this study show that time-in-store is not a factor affecting the recall of temporal information. Indeed, when only the criterion time length (either the 1 second or the 4 seconds time length) was stored, recall performance after 15 seconds of rest was not statistically different from immediate recall performance for all dependent measures. Therefore, time has no effect on the recall of temporal information. This is not in accordance with the results obtained in Experiment 4, but certainly supports the data found in Experiment 7. As in the latter study, when subjects reproduced time lengths of one and four seconds under an experimenter-defined rehearsal and specific instructions, no difference between an immediate recall and recall after 15 seconds retention intervals

was demonstrated.

The Time-in-Store Factor: Two Time Lengths are Stored Together

In proposing his acid bath theory, one reason Posner (1966) felt that time-in-store would enhance interference is that the information would decay over time-in-store and hence, would be more susceptible to interference. Applied to temporal information, this reasoning would predict that, if two time lengths were stored together, interference effects would be more apparent after a delay interval than at immediate recall.

Interference effects were not demonstrated for both time lengths. When two time lengths were stored together, the recall performance of the criterion time length after 15 seconds of rest did not differ from that of immediate recall for all dependent variables. Such results are indicative of the fact that time-in-store did not activate interference between the stored items as would have been predicted from Posner's acid bath theory.

Order of Responses

When two time lengths were stored together, subjects' recall performance of the criterion time length was the same whether it was presented first or second. Subjects' storage capacity could then accomodate at least two time lengths. A verification was necessary to determine

whether or not, in the successive presentation of the two time lengths, the second one could be stored intact. The subjects were operating within the limits of the memory span and when two time lengths were presented to them, both time lengths were stored intact.

<u>Summary of Section 4</u>

The effect of temporal interpolated activities on temporal recall were investigate in Section 4. Hopefully, if temporal interpolated material interfered with previously stored temporal information, the factors governing this interference could be described.

The effect of inserting an interpolated duration under a conscious time estimation cognitive strategy produced interference on the reproduction of a four seconds time length after a retention interval of 15 seconds. The systematic differences obtained when two time lengths were stored as opposed to when only the criterion time length was stored were representative of the fact that the subjects use different strategies going from one condition to the other.

The effect of an interpolated time length under a mental counting cognitive strategy did not activate interference between the stored items for short time lengths.

The subjects, using conscious time estimation and mental counting cognitive strategies, could accomodate at least two time lengths. Consequently one could assume that they were operating within the limits of immediate memory span.

General Discussion

The main purpose of this series of ten studies was to determine the short-term retention characteristics of temporal information. A second purpose was to determine the constraints and causes leading to a loss of temporal information when forgetting occurs. A time estimation-reproduction task was used (Bindra and Waksberg, 1956). Temporal durations of eight seconds or less were utilized. Two factors were investigated: (a) time-in-store, and (b) interference (capacity, proactive and structural). These factors were examined under conscious time estimation and mental counting cognitive strategies. Conscious time estimation cognitive strategy was involved when subjects were asked to consciously estimate time without the use of time aiding techniques. Mental counting cognitive strategy was involved when subjects estimated time by subdividing the interval into a sequence of short durations (subjective time units), for example by counting rhythmically "one, two, three ...".

This research program was divided into four sections. The perceptual characteristics demonstrated in human time estimation under conscious time estimation as opposed to experimenter-defined cognitive strategies were examined in Section 1 (Experiment 1). The effects of time-in-store and capacity interference factors on time

estimation were investigated in Section 2 (Experiments 2, 3 and 4). Rehearsal and proactive interference were the two factors considered in Section 3 (Experiments 5, 6 and 7). Finally, the effects of structural interference on time estimation were questioned in Section 4 (Experiments 8, 9 and 10).

A distinction was made between the perception, and the memory of time. The perception of time referred to the more or less immediate experience of temporal durations while the memory of time referred to the experience of temporal durations in retrospect (retention intervals which are less than 60 seconds) (Fraisse and Florès, 1956).

Difference between the perceptual characteristics demonstrated in human time estimation under conscious time estimation cognitive strategy as opposed to experimenter-defined cognitive strategies for temporal durations (less than four seconds) were determined in Section 1. The experimenter-defined cognitive strategies provided better results than the conscious time estimation cognitive strategy. That experiment led to the conclusion that the use of different cognitive strategies (different cues) produced different results for the perception of time. This finding has been reported previously by Buckolz and Gervais (1976), and Buckolz and Guay (1975). It was on that basis that conscious time estimation and mental counting cognitive strategies were chosen to be examined for their retention characteristics (retention of time) in the other three

sections. Although a wide array of information is available to aid in temporal reproduction, studies of temporal short-term memory have given little attention to the specific cue (or cues) the subject may use during recall. Researchers might have attempted to isolate these cues for the perception of time, but did not determine their retention characteristics, then failure to adequately control for the use of different cues is bound to lead to conflicting and uncertain results.

This research program revealed a number of interesting results on the short-term retention of temporal information (Sections 2, 3 and 4). The most important result and one which was reflected throughout this series of studies was that time-in-store and interference (structural) were crucial factors. This finding is in opposition to the human time estimation literature. The importance of these two factors confirmed the distinction made between the perception and the memory of time. However, differences between the two processes were only perceived when specific cognitive strategies and durations were used by the subjects.

Time-in-Store Factor

Studies on time estimation prior to this series of experiments have not led to the conclusion that the memory for time fades over an unfilled retention interval.

Retention intervals from 0.4 up to 120 seconds were used by DuPreez (1967), Hawkes, Ray and Hayes (1974), Kowalski (1943), McNutt and Melvin (1968), Pöppel (1973), Richards and Livingston (1966) and Vroon (1970).

Section 2 provided results contrary to the above human time estimation studies. Time-in-store was an important factor when subjects reproduced temporal durations (eight seconds or less) under either conscious time estimation or mental counting cognitive strategies. The retention characteristics demonstrated under the mental counting cognitive strategy were however, superior to those under conscious time estimation cognitive strategy.

Temporal information for short durations (four seconds or more) was rapidly lost as a function of rest period under a conscious time estimation cognitive strategy. The reproduction of those temporal durations was quite similar to the reproduction of movement information when distance was the only reliable cue (Laabs, 1971). Short temporal durations did not appear to be rehearsable. The utilization of an experimenter-defined rehearsal (covert rehearsal) for those durations had no greater advantage than a subject-defined rehearsal (Section 3). However, the retention of time had no apparent effect on the recall of temporal information when subjects rehearsed covertly (Section 4).

A theory of temporal memory was proposed which could account for the loss of temporal information for

those durations. It was suggested that temporal durations of four seconds or more exceed immediate memory span and suffer accordingly. Such a suggestion would indicate that there is a duration constraint on temporal short-term memory (STM). When exceeded, the memory for the particular duration is degraded. The concept of a memory buffer was used as a near analogy (Atkinson and Shiffrin, 1968). In this instance, the maximum length of any given temporal event, as well as the total number of to-be-remembered items may be limited. The increase in variablility demonstrated after a short unfilled retention interval for temporal durations of four seconds or more suggests that there is a maximum temporal memory span.

Although it was proposed that temporal durations (eight seconds or less) under a conscious time estimation cognitive strategy may be encoded verbally, further confirmation will be needed. Perhaps, a reconstruction (Michon, 1975) or a symbolic representation of the interval (Michon, 1972) which has been used as a synonym for verbal encoding in the literature might be appropriate for temporal durations of four seconds or more. Temporal durations which are less than four seconds might not be verbally encoded but stored in a direct representational form. If this is true, then investigations into the genesis of temporal codes as a function of time would need to be pursued.

Temporal information for very short durations (four seconds or less) was rapidly lost as a function of

rest period (subject-defined rehearsal) under a mental counting cognitive strategy. An experimenter-defined rehearsal (overt rehearsal) during the retention interval, did not enhance recall performance any more than a subject-defined rehearsal (Section 3). However, the addition of specific instructions with an experimenter-defined rehearsal eliminated the loss of temporal information. Rehearsal strategies were attributed to the facilitation of temporal information for those durations. It seems that providing subjects with the following instructions enhanced recall performance. The specific instructions were that the subjects should retain a 'number' of subjective units as well as the 'length' of the subjective time unit (counting rate) under such cognitive strategy.

The retention characteristics between conscious time estimation cognitive strategy and mental counting cognitive strategy were found to be quite different. The cues (visual + verbal) used under mental counting cognitive strategy provided better results than the cues (visual) used under conscious time estimation cognitive strategy. If recall exactness is the critical outcome, a mental counting cognitive strategy should be utilized under the specific instructions previously mentioned. When subjects used a mental counting cognitive strategy they were in effect, encoding the temporal duration in a verbal form (i.e. the 'number' of subjective time units). However,

the internal code for the 'length' of the subjective time unit remains to be investigated (Vroon, 1976).

Interference Factor

Studies on time estimation prior to this series of experiments have not led to the conclusion that capacity interference was operating on the tbri for time (Hawkes, Ray and Hayes, 1974; and Kowalski, 1943). Structural interference was demonstrated in Turchioe (1948) study on time estimation. Proactive interference has not been the subject to any investigation for temporal information.

Section 2 provided results in agreement with the human time estimation literature for capacity interference. Backward counting was the non-temporal interpolated activity used as interference material. Removal of the subjects' attention during the retention interval produced similar results as when they had to reproduce under an unfilled retention interval for both cognitive strategies.

Proactive interference effects were not demonstrated under conscious time estimation and mental counting cognitive strategies (Section 3).

Structural interference effects were found to be operating when subjects reproduced under a conscious time estimation cognitive strategy (Section 4). The effect of inserting an interpolated duration produced interference on the reproduction of a four seconds duration after a

15 seconds retention interval. The systematic differences obtained when two durations (one and four seconds) were stored as opposed to when only the criterion duration (four seconds) was stored were representative of the fact that the subjects use different strategies going from one condition to the other. Because of that fact, when subjects use a differential judgment to reproduce one of two durations, their performances deteriorated as a function of time-in-store. Further, the similarity of the stored material did not affect immediate recall performance for both cognitive strategies. This finding is contrary to Turchioe (1948) results. Finally the immediate memory span for temporal information appears to be able to accomodate at least two temporal durations when the subjects use conscious time estimation and mental counting cognitive strategies.

These results indicate again that the perception of time and the memory of time are quite different processes when a conscious time estimation cognitive strategy is used. Structural interference was demonstrated following a short retention interval but did not appear when subjects had to immediately produce from memory one of two temporal durations stored at input. The manner (i.e. strategies used by the subjects) in which subjects retain temporal information seems to be a very important factor. One could suggest that different cognitive strategies would be tailored to provide the most accurate recalls for a

variety of temporal tasks.

Based on the results of this research program, further experimentation should be done on the encoding of temporal information.

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